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Vol. III

TRANSCRIPT OF RECORD

(Pages 557 to 782)

Supreme Court of the United States

OCTOBER TERM, [redacted] 1946

No. [redacted] 24

HALLIBURTON OIL WELL CEMENTING COMPANY, PETITIONER,

vs.

CRANFORD P. WALKER AND CRANFORD P. WALKER, D. A. WALKER, ET AL., DOING BUSINESS AS DEPTHOGRAPH COMPANY, COPARTNERSHIP

ON WRIT OF CERTIORARI TO THE UNITED STATES CIRCUIT COURT OF APPEALS FOR THE NINTH CIRCUIT

PETITION FOR CERTIORARI FILED AUGUST 2, 1946.

CERTIORARI GRANTED OCTOBER 14, 1946.

Office - Supreme Court, U. S.
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CLERK

TRANSCRIPT OF RECORD
IN SIX VOLUMES

IN THE

Supreme Court of the United States

October Term, 1945

No. 290

HALLIBURTON OIL WELL CEMENTING COMPANY, a Delaware corporation,

Petitioner,

vs.

CRANFORD P. WALKER and CRANFORD P. WALKER, D. A. WALKER, ROBERT P. MILLER and MILO C. KETCHUM, doing business as Depthograph Company, a copartnership,

Respondents.

VOLUME III

Book of Exhibits (Plaintiffs' Exhibits)

Pages 587 to 781

UPON PETITION FOR A WRIT OF CERTIORARI TO THE UNITED STATES CIRCUIT COURT OF APPEALS FOR THE NINTH CIRCUIT

Rotary Colorprint, 651 Howard Street, San Francisco

No. 10513

United States
Circuit Court of Appeals
For the Ninth Circuit.

HALLIBURTON OIL WELL CEMENTING COMPANY, a Delaware corporation,

Appellant,

vs.

CRANFORD P. WALKER and CRANFORD P. WALKER, D. A. WALKER, ROBERT P. MILLER and MILO C. KETCHUM, doing business as Depthograph Company, a copartnership,

Appellees.

CRANFORD P. WALKER and CRANFORD P. WALKER, D. A. WALKER, ROBERT P. MILLER and MILO C. KETCHUM, doing business as Depthograph Company, a copartnership,

Appellants,

vs.

HALLIBURTON OIL WELL CEMENTING COMPANY, a Delaware corporation,

Appellee.

Transcript of Record
In Five Volumes

VOLUME III
Book of Exhibits
(Plaintiffs' Exhibits)
Pages 587 to 781

Upon Appeals from the District Court of the United States for the Southern District of California, Central Division

Rotary Colorprint, 590 Folsom St., San Francisco

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PLAINTIFF'S EXHIBIT No. 1

Walker Patent No. 2,156,519

[Endorsed]: Filed Oct. 6, 1942.

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In suit

May 2, 1939. C. P. WALKER 2,156,519

MEANS FOR MEASURING THE LOCATION OF OBSTRUCTIONS IN WELLS

Filed Sept. 7, 1937 2 Sheets-Sheet 1

FIG. 1.

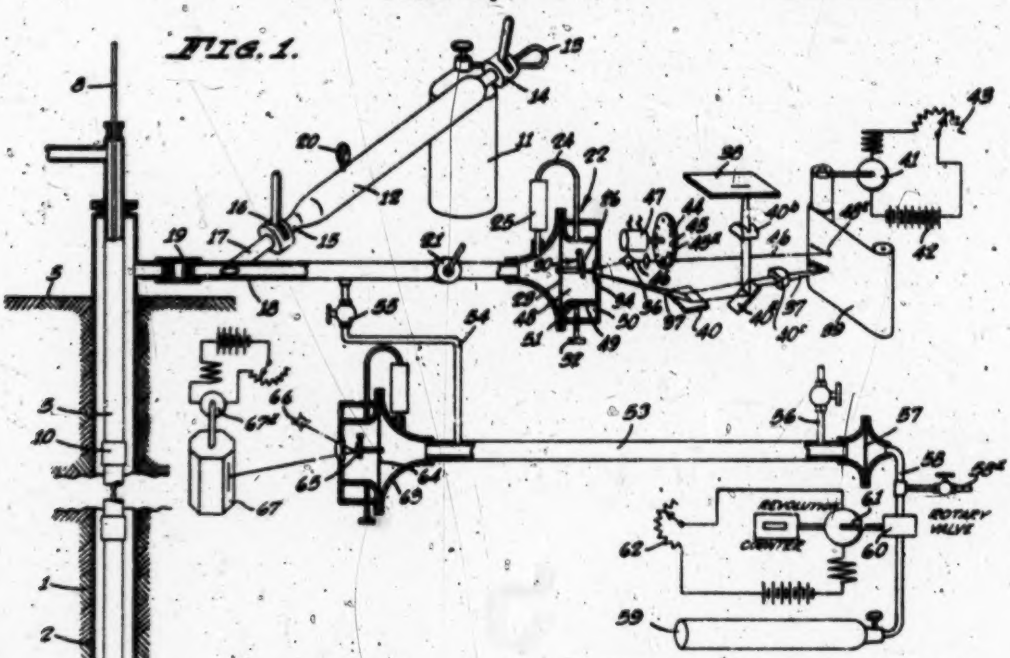

FIG. 2.

FIG. 3.

FIG. 4.

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May 2, 1939. C. P. WALKER 2,156,519

MEANS FOR MEASURING THE LOCATION OF OBSTRUCTIONS IN WELLS

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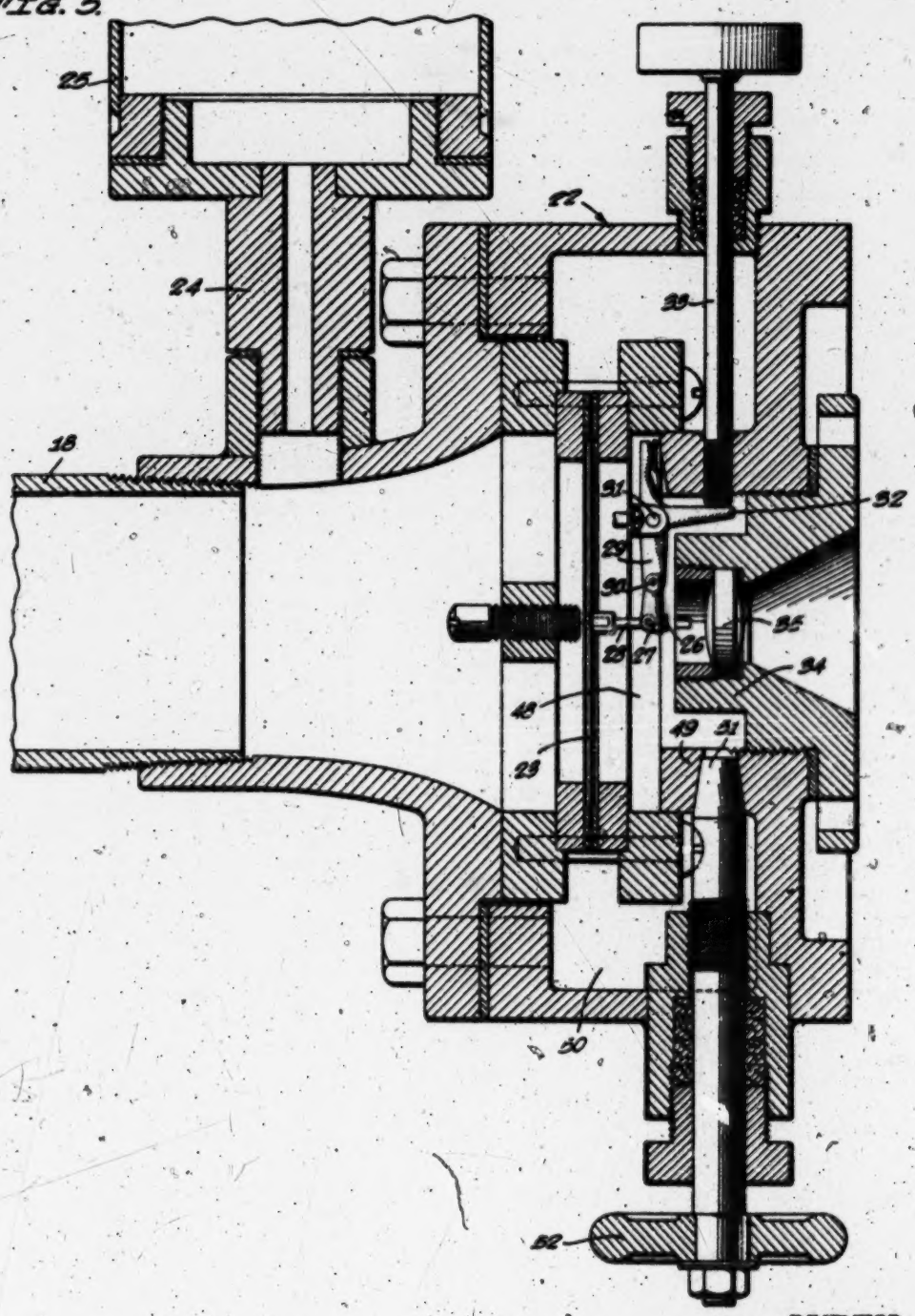
FIG. 5.



INVENTOR.
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BY Harold R. Huntington
ATTORNEY.

Patented May 2, 1939 2,156,519

UNITED STATES PATENT OFFICE

2,156,519

MEANS FOR MEASURING THE LOCATION OF OBSTRUCTIONS IN WELLS

Cranford P. Walker, San Marino, Calif.

Application September 7, 1937, Serial No. 162,999

17 Claims. (Cl. 181—0.5)

My invention relates to devices for measuring the location of obstructions in deep wells, such as oil wells, and has particular reference to apparatus for determining the location below the ground surface of the liquid level in the well or the location of tools, pipe sections, couplings or other devices which constrict the well bore.

During the active life of an oil well it is desirable from time to time to determine the location of the fluid level within the well for the purpose of determining the type of pumping apparatus most desirable to be used, determining the rate of flow of oil into the well, and for making other determinations desirable in the most efficient operation of the well.

Prior methods of determining the location of the fluid level or the location of other obstructions in the well have been generally of two types, one in which measuring apparatus has been lowered from the ground surface to determine by the length of cable or line extended into the well the depth or location of the fluid or other obstructions encountered by the instrument as it is lowered. Among devices to be lowered into the well is also included a pressure recorder which may be lowered into the well on a wire, the length of which is metered to determine the static pressure in the well at different levels, a variation of which includes a pressure recorder with a clock driven chart lowered on the bottom of the pump to obtain a record of the operating pressures or levels of the fluid. A further variation is that of lowering a bailer upon a rope and either measuring the wetted surface of the rope or repeatedly lowering the bailer until it brings up fluid, measuring the length of the line upon such occurrence. The other method is that of producing sound waves in the well and noting the elapsed time between the introduction of the sound and its return as an echo from the surface of the fluid or other obstruction encountered.

Neither of these methods is satisfactory, the first having the disadvantage of requiring the removal of oil flow tubing, sucker rods and other apparatus normally disposed in the well prior to the time the instrument is inserted in and lowered into the well, requiring a considerable length of time both for the removal of such apparatus, the reinsertion of the apparatus, and the making of the actual measurement. The other method is unsatisfactory primarily because of the relatively low intensity or energy which can be employed in the sound wave so that the echo received back is of such low energy as to prevent its accurate detection and, further, little or no distinction is made by reason of such low energy between various types of obstructions encountered by sound wave.

A third method, namely, that of introducing a shock of relatively high intensity into the well, creating thereby a pressure wave which travels through the well, and measuring the elapsed time between the introduction thereof and the echo thereof, to give an indication of the depth of the fluid level and other obstructions, has been introduced, one form being that of creating an explosion in the well, another form being illustrated and described in United States Letters Patent No. 2,047,974, issued to Harold J. Wyatt and Paul E. Lehr on July 21, 1936. This latter method has the desirable characteristic of permitting the employment of relatively high intensity in the wave or impulse produced in the well and it is an object of my invention to improve upon the method disclosed in that patent and to eliminate or materially reduce factors of error encountered in the employment of that method.

Another object of my invention is to provide a device for the measurement of the location of fluid level or other obstructions in a well bore in which the pressure impulse introduced into the well produces an indication both of the fluid level and of the location of other obstructions in the well bore.

Another object of my invention is to provide an apparatus of the character set forth in the preceding paragraph wherein the same pressure impulse introduced into the well to measure the fluid level or the location of other obstructions is employed to determine the velocity of the wave in the particular media encountered in the well.

Another object of my invention is to provide an apparatus as set forth in the preceding paragraph wherein, knowing the location of one or more obstructions, tools or other devices in the well bore, the velocity of the wave within the well bore may be accurately determined from echoes produced thereby and enabling an operator to determine the unknown location of the fluid level by the mere measure of the elapsed time between the introduction of the impulse into the well and the reception of a distinguishable echo from the fluid level, without necessitating introduction of corrective factors or other separate measurement of and determination of the character of the media in the well.

Another object of my invention is to provide an apparatus for determining the location of fluid levels in well bores in which the location of and the number of tubing sections in the well may be determined by the same pressure wave

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created to measure the depth or the location of the fluid level.

Other objects of my invention will be apparent from a study of the following specifications, read in connection with the accompanying drawings, wherein

Fig. 1 is a diagrammatic view illustrating a typical well cross section and the location and character of the apparatus required for determining the fluid level or location of other obstructions in the well in accordance with my method;

Fig. 2 is a diagrammatic view illustrating the type of record or indication which may be made with my method in its simplest application;

Fig. 3 is a diagrammatic view similar to Fig. 2 and illustrating the type of record or indication which may be made with my method but in which echoes produced by intermediate obstructions are not amplified;

Fig. 4 is a diagrammatic view similar to Figs. 2 and 3 and illustrating the type of record or indication which may be made with my method, including the amplification of echoes from intermediate obstructions; and

Fig. 5 is a vertical sectional view taken through one form of mechanical pressure responsive device which may be employed in my method.

The method disclosed in United States Letters Patent issued to Wyatt and Lehr, hereinbefore referred to, is briefly that of introducing into a well bore a pressure impulse, either positive or negative, which may have any desired frequency as by the introduction into the well of a quantity of gas of known pressure and volume, the introduction of this impulse into the well producing a wave which will travel down the well until it encounters the fluid surface in the well and then the wave will be reflected and will travel back up the well to the ground surface where the echo or return wave may be detected, the measurement of the elapsed time between the production of the impulse and the arrival at the ground surface of the echo constituting a measure of the location of the fluid level by the simple calculation of the elapsed time multiplied by the rate of travel or the velocity of the wave in the well. In making such calculations, it is correctly assumed that the velocity of the wave will be the same as that of a sound wave. In air at normal temperatures and approximately sea level pressures, this rate would be 1100 feet per second but the gaseous content or media in the well is ordinarily not the same as air and correction must be made for the density, temperature or other characteristics of the particular media encountered in the well, it being well known that the higher the temperature or the lower the density of the gaseous media through which the impulse travels, the greater the velocity of the wave.

In employing the method as set forth in the said patent, an approximation of the fluid level may be readily determined and this approximation or measurement may be determined in a relatively short length of time, without requiring the removal or disturbance of any of the apparatus contained within the well bore. However, to determine the fluid level with considerable accuracy, the rate of travel of the wave in the particular media encountered in any particular well must be known or must be determined since the density, temperature and character of the gaseous media in wells varies in each different oil field and in each individual well. I provide means for readily determining at any particular well the velocity of the wave in that particular well, which may be arrived at as follows:

In Fig. 1 I have illustrated a typical oil well comprising the earth bore 1, usually lined with casing 2 or pipe of relatively large diameter, extending from the ground surface at 3 to the oil bearing sands at 4 where the casing is either perforated or is provided with a perforated liner through which the oil from the sands may enter to the interior of the casing. The casing is, of course, constructed of a plurality of lengths of pipe secured together by couplings or collars in any well known manner. A second pipe or string of pipes extend down through the casing 2, this string of pipe being known as the oil flow tubing, indicated at 5, extending from the ground surface down to a position disposed below the level of the fluid in the well, which is indicated at 6, the lower end of the tubing string 5 having a pump 7 of any desired character located therein. Such pumps are usually operated by means of a string of sucker rods 8 which extend upwardly through the tubing string 5.

It is the common practice to employ in the tubing string 5 a tubing catcher 9 which may be of any of the well known constructions, the tubing catcher being usually located a relatively short distance above the level of the fluid in the well so that should the tubing string break the tubing catcher 9 will grip the casing and prevent complete destruction of the tubing string. One or more of the tubing catchers 9 may be distributed throughout the length of the tubing string 5.

The tubing string 5 is constructed of a plurality of lengths of pipe coupled together by means of collars 10, which collars are usually of somewhat larger outside diameter than the outside diameter of the tubing from which the oil flow tubing is made.

Hence it will be noted that in the ordinary oil well there are a plurality of obstructions, each of which is capable of receiving and reflecting a sound wave or pressure wave passing down through the well, these obstructions including the fluid surface 6, the tubing catcher 9 and each of the collars 10 of the tubing string.

In most wells the length of the tubing string between the ground surface 3 and the pump 4 is known, that is, records are usually kept showing the length of each tubing string section and the number of such sections located within any given well. Particularly, records are usually kept as to the location along the tubing string of the catcher 9 so that by referring to these records an absolute calculation or determination of the distance between the ground surface and the tubing catcher or liner top is known. Hence to determine the location of the fluid level 6, it is only necessary to produce in the well a pressure impulse which will create the low frequency wave, and then translate the echoes received from the well in terms of echo impulses received from the tubing catcher or liner top and from the liquid surface. By comparing the time lapse between the production of the pressure impulse and the receipt of the echo from the tubing catcher with the time lapse between the creation of the pressure impulse and the receipt of the echo from the fluid surface, a positive and accurate measurement of the location of the fluid level may be obtained. That is, if the known location of the tubing catcher is 5000 feet below the fluid sur-

face and it is desired to know the height of the fluid in the well, all that is necessary is to produce a pressure impulse, note or record the echo from the tubing catcher, and note or record the echo received from the fluid surface. The time lapse between the creation of the pressure impulse and the receipt of the echo from the tubing catcher denotes the velocity of the pressure wave in the particular media encountered in that particular well so that by measuring the additional elapsed time between the receipt of the echo from the tubing catcher and the receipt of the echo from the fluid surface, an accurate measurement may be obtained and no compensation need be made for possible errors due to different velocities of waves in different media because the mean velocity of the wave from the ground surface to the tubing catcher and return is exactly the same as the mean velocity of the wave from the ground surface to the fluid surface and return.

The only item which must be provided for is that of producing a pressure wave echo of such magnitude and of such character that the echo from the tubing catcher can be distinguished from the echo received from the fluid surface.

As illustrated in Fig. 1, this distinction may be readily made by providing a suitable source of fluid pressure indicated at 11 which may be a tank, compressor or other source of fluid pressure at any desired value. It follows, of course, that the pressure impulse which must be produced in the well must be at a greater pressure than the pressure of gases in the well so that the pressure source 11 must be capable of delivering a pressure impulse having a considerable differential over the static pressure of gases in the well or flowing therefrom. For example, if the well gases at the surface of the well are at a pressure of 500 pounds per square inch, the source of fluid pressure 11 must be capable of delivering, say, 600 pounds per square inch or more in order to create a pressure impulse of, for example, 100 pounds pressure differential.

The pressure source 11 is illustrated as being coupled to a pressure chamber 12, one end of which is connected as by means of tube 13 and valve 14 to the pressure source 11, while the opposite end of the pressure chamber 12 is connected by means of a nipple 15, a quick opening valve 16 and a nipple 17 to a length of pipe 18 which is in turn coupled as indicated at 19 to the well casing 2. The pressure chamber 12 is preferably provided with a suitable indicating pressure gage 20 by which the pressure within the pressure chamber 12 may be readily measured. Thus for the production of the pressure wave all that is necessary is to close valve 16, open valve 14 and allow pressure to be built up in the pressure chamber 12 to the desired pressure value, say, 600 pounds per square inch. Then the valve 14 is closed and valve 16 opened, allowing an impulse of 600 pounds per square inch to be injected into the well casing (the static pressure in which is, for example, 500 pounds per square inch).

A receiving device for receiving and registering the echoes of the pressure impulse from the various obstructions within the well is illustrated as including the pipe 18 and pressure responsive device coupled thereto through a valve 21 to a diaphragm chamber 22, permitting a flexible diaphragm 23 to be placed into communication with the casing 2 whenever the valve 21 is opened. To control the sensitivity of response of the diaphragm 23 and in order to prevent undue distortion of the diaphragm 23 by the static pressure in the well and to avoid damage which would result therefrom, I prefer to allow the static pressure in the well casing 2 and pipe 18 to be equalized on both sides of the diaphragm 23 as by providing a by-pass 24 providing a restricted passage through which gas pressure in the chamber 22 on one side of the diaphragm may pass to the opposite side of the diaphragm, the filter 25 being interposed in the by-pass if desired to dry out the gas and prevent undue corrosion of the more delicate parts of the device contained in the diaphragm chamber 22. Attached to the diaphragm 23 is a mirror 26, preferably connected as shown in Fig. 5 upon a link 27, one end of which link is coupled by means of a rod 28 to the diaphragm 23. The opposite end of the link 27 is preferably connected to one arm of a bellcrank lever 29, as indicated at 30. The bellcrank lever 29 is pivoted as at 31 to any desired portion of the metal comprising the diaphragm chamber 22, another arm of the bellcrank lever 29 extending as indicated at 32 to be engaged by an adjusting rod 33 so that by operating the adjusting rod 33 the fulcrum point 30 of the link 27 may be varied as desired to properly position the beam on a recording chart.

In the front wall 34 of the diaphragm chamber 22 I mount a lens 35, through which light from a suitable light source 36 may pass into the chamber 22 to be reflected by the mirror 26, the reflected beam 37 passing back through the lens 35, as a ribbon beam which may be reflected or directed upon a ground glass screen 38 and upon a recording chart or strip of sensitised tape 39 to make a permanent record of the path described by the light beam 37. Suitable reflectors, such as indicated at 40, may be employed to direct the beam in any desired direction while a reflector 40a may be interposed in a portion of the ribbon beam 37 to direct a portion thereof upon the screen 38, suitable condenser lenses 40b and 40c being interposed in the beam to draw the same to a point beam upon the screen 38 and tape 39.

Thus as the pressure within the casing 2 is varied as by the pressure wave resulting from the pressure impulse created within the casing 1, the mirror 26 will be moved, the amplitude of its movement representing the amplitude of the pressure variation. As the echo of the pressure impulse from any obstruction within the well is received upon the diaphragm 23, the mirror 26 will be moved in accordance with the amplitude of the echo impulse and will cause the echo impulses to be registered for observation, both by directing the light beam 37 upon the ground glass 38 where the amplitude of the echo may be visually observed and, by directing the light beam 37 upon the recording tape 39, a permanent record of the pressure wave which is created within the casing 2 may be made and this wave or chart will show peaks of varying amplitude, each of which peaks represents an echo from a particular obstruction within the well, either the tubing collars 18, the tubing catcher 8 or the fluid surface 6.

The sensitised strip 39 may be arranged to be driven at any desired speed by means of a variable speed motor 41 coupled to a suitable source of current 42 through a rheostat or other speed adjusting device 43 so that the tape or strip 39 may be driven at variable speeds.

By employing some device which will produce

upon the record strip 39 a time lapse measurement, a direct comparison between the path described by the light beam and the lapse of time may be accomplished. I prefer to provide such mechanism including means for producing upon the strip 39 a series of dots or marks, each of which represents a fraction of a second, the line of dots or marks extending substantially parallel to the general direction of the wave chart described by the light beam 37. This may be readily accomplishing by providing a disc 44 having a plurality of openings 45 therein adapted to be rotated in the path of a secondary light beam 46 emanating from the light source 36. The light beam 46 passing through the openings of the disc 44 may be projected upon the same sensitized strip 39 to describe a series of marks thereon, one for each of the openings 45. One of the openings 45a is preferably larger than the remainder so that upon each revolution of the disc 44 a distinguishing mark will be produced. Thus by providing ten openings 45, a series of marks 48a may be produced upon the record strip 39 representing ten equal divisions. The tenth mark being produced by the large opening 45a is of greater length or of greater size or in some other manner distinct from the remaining nine marks. By providing the disc 44 with any suitable time mechanism such as a synchronous motor 47, the marks produced upon the charts will represent lapse of time; for example, each mark representing $\frac{1}{10}$ of a second while the space between the distinct marks will represent lapses of one second each.

Due to the fact that the depth of wells varies considerably and, further, due to the fact that conditions of obstruction or constriction of the space between the well casing 2 and the tubing string 5 varies considerably in different wells, the same pressure differential cannot be used successfully in all wells and it is necessary to vary the pressure impulse through considerably wide limits, dependent upon the conditions encountered at a particular well. For this reason I prefer to direct a portion of the beam 37 upon the ground glass screen 38 so that by firing one charge of gas pressure into the well and observing the path described by the light beam, a determination of whether or not the correct pressure impulse is being used may be made. For example, one pressure impulse which is estimated to be correct for a given well may not produce a sufficient fluctuation in the echo waves received from the tubing catcher and the fluid surface, and a higher pressure or greater quantity of gas must be used in order to create the desired impulse. Thus by observing the effect of a succession of pressure impulses liberated into the well, the person making the survey will be able to determine which of the echoes rebounds from the tubing catcher and which of the echoes rebounds from the fluid surface.

The pressure wave velocity in different wells varying through wide limits, it is desirable to provide some regulation controlling the sensitivity of response of the diaphragm 23 to pressure variations and also to control the sensitivity of the diaphragm to distinguish between echoes from different obstructions in the well. In some surveys it may be desirable to render this diaphragm more sensitive than in making surveys of other wells under other conditions, particularly for the purpose of allowing the amplitude of movement of the light beam in response to collar echoes to be substantially the same in the surveying of different wells, and I provide a ready means for varying the sensitivity of response of the diaphragm 23 by providing in the pressure chamber 22 two distinct chambers or compartments. One of these compartments or chambers 48 may be formed centrally of the diaphragm chamber 22 as by providing an annular division wall 49, the chamber 48 being disposed on the forward side of the diaphragm 23 and constituting a chamber of fixed volume. The second of these chambers 50 may be provided between the annular wall 49 and the exterior wall of the diaphragm chamber 22, the volume of this chamber being relatively great as compared with the volume of chamber 48. By providing an orifice 51 in the wall 49 intercommunicating chambers 48 and 50 and providing a valve 52 for regulating the effective size of this orifice, the effective volume of the chamber communicating with the forward face of the diaphragm 23 may be varied in small increments so that the diaphragm 23 may be so regulated as to respond with varying degrees of sensitivity.

The typical desired configuration of the path described by the light beam 37 is indicated in Fig. 2 wherein *a* represents the path described by the light beam as a result of the pressure wave created by a discharge of gas from the chamber 12 into the well casing. From an inspection of the line *a*, it will be noted that this line is a relatively straight but somewhat wavy line, having distinct peaks at *b*, *c* and *d*. The peak *b* is that which will be produced by the deflection of the diaphragm 23 when the impulse of gas from the chamber 12 is liberated into the casing 2. At a predetermined time thereafter, dependent upon the velocity of the wave in the particular well, a peak *c* will be produced as a reflection from the tubing catcher 9, while at a predetermined time thereafter an additional peak or series of peaks will be produced at *d* as a reflection of the wave from the fluid surface.

Thus by observing the effects of a series of pressure impulses of different intensity or pressure, the operator may determine which impulse is most desirable to produce the distinctly recognizable and differentiatable peaks *c* and *d*, allowing him to differentiate between echo from the tubing catcher and the echo from the fluid surface. As hereinbefore stated, knowing the depth or location of the tubing catcher 9, the comparison of the elapsed time between the peaks *b* and *c* and the elapsed time between the peaks *b* and *d*, an accurate determination of the fluid level may be produced.

After the most desirable pressure impulse has been determined, the motor 41 may be set into action and a permanent record of the path described by the light beam may be made upon the sensitized film 39 with assurance that the various peaks *b*, *c* and *d* will be readily distinguishable upon the diagram so produced.

As will be observed from an inspection of Fig. 2, the diagram on the strip 39 also shows the plurality of spaced dots or other means of indicating elapsed time, such series of dots being indicated at 48a.

Having made a diagram as indicated in Fig. 2, a direct measure and determination of the fluid depth may be achieved. Also it will be observed that by selecting impulses of the desired magnitude, reflections from other obstructions in the well may be noted and recorded, thus assisting in the location and determination of other re-

strictions as well as a measurement of the fluid level.

For example, each of the collars 18 of the tubing string will produce a distinct echo differentiable from the echoes from other sources. This allows the accurate measurement of the fluid level in a well where, by reason of failure to keep records or loss of records, the location of the tubing catcher is not known or wherein the catcher is submerged or is omitted. For example, in some wells tubing has been drawn out and replaced by other tubing and no record has been made of the lengths of tubing drawn out or the lengths of each section drawn out or the lengths or number of tubing section employed to replace them so that to merely compare the time distance between the peaks *b* and *c* would not give a true indication of the velocity of the wave in the particular well. However, if it is reasonably assured that each of the tubing lengths is approximately the same, and the usual practice in oil wells is to employ tubing lengths in a given well, all of which are the same, an indication of the number of tubing lengths located within any given well, multiplied by the average length of a tubing section, will give a true measure of the location of the tubing catcher or the location of the pump or other device which constitutes an obstruction in the well. Thus, for example, by selecting a desired pressure impulse, by comparison of a succession of pressure impulses and the waves produced thereby, upon the ground glass 38, a wave or line of the character indicated at *a* in Fig. 3 may be produced wherein, though *a* is still wavy, it is produced by a series of peaks *e*. By counting the number of these peaks, each of which represents a reflection back from a collar 18, the number of lengths of tubing between the peaks *b*, *c* and *d* may be determined.

However, in actual practice there are so many other possible disturbances in the well as to create peaks similar to *e* which are not readily distinguishable therefrom and I prefer to provide a means for tuning out other vibrations, harmonics or other disturbances so that the peaks *e* will accurately represent only reflections from the collars 18.

As will be understood, the introduction into a sound wave or multiplicity of sound waves of another wave tuned with one of the waves, produces a beat or amplification of certain of these waves differing in frequency from the first wave will be damped out. By selecting the correct length for the pipe 18, that is, by selecting the correct distance between the casing 2 and the diaphragm 23, a tuned wave may be produced which will effect the movements of the diaphragm 23. Since it is desired to count the number of tubing collars, all that is necessary is to lengthen or shorten the pipe 18 until it is tuned to one of the harmonics of the impulses or echoes produced by the collars 18. From experience it has been found that selection of the pipe 18 of approximately one-third of the length of a section or joint of the tubing 9, a third harmonic is is produced which beats with the impulses echoed from the tube collars 18 to produce magnified or amplified peaks *e* and permits the ready distinguishing of the impulses produced by the collars 18 from other impulses.

I prefer, however, to employ in the length of the pipe 18 an adjustable coupling 19 which allows the accurate lengthening or shortening of the pipe 18 until, by observing the path of the light beam upon the ground glass 38, a distinct pattern is made represented by the line *a* on Fig. 4, in which each of the intermediate peaks *e* is amplified as indicated in Fig. 4 so that it is readily recognizable.

The adjustment of the coupling 19 should be made until, with a given pressure impulse, a uniform deflection of the mirror 36, that is, a uniform amplitude of the peaks *e*, is achieved, and by observing this upon the ground glass 38 the operator will note when the pipe 18 is of such length as to be "tuned" with the tubing lengths.

Thus, even though the location of the tubing catcher is not known, if the average length of tubing section is known, the production upon the strip 39 of a diagram such as shown in Fig. 4 allows the counting of each of the collars 18 and a clear understandable record is made of the length of tubing string between the impulses *b*, *c* and *d*, permitting the quick and accurate location and determination of the exact level of the fluid in the well.

Where the tubing lengths are not known and where the location of the tubing catcher is not known, or where the catcher and liner top are submerged, a quick and ready method of determining the velocity of the pressure wave through the particular gaseous medium encountered in a particular well may be made by employing an elongated tube or pipe 83 coupled as by means of a short pipe 84 to the pipe 18 and controlled by a valve 85 in such manner as to permit gas from the casing 1 to flow through the pipe or tube 83, thus providing in the pipe 83 an atmosphere corresponding to the atmosphere or gaseous medium in the casing 1. An open exhaust pipe 86 leads from the opposite end of pipe 83 open to the atmosphere or connected to a gas flow line so that the pressure within the pipe or tube 83 will remain substantially constant as of the value of the gas in the casing 1. Near one end of the tube 83, a diaphragm 87 may be provided and arranged to be vibrated at any desired frequency as by coupling the diaphragm 87 by a pipe 88 open to the atmosphere at 88a, to a source of fluid pressure, such as compressed air, indicated at 89. A rotary valve 90 is interposed in the pipe 88 and arranged to be driven by means of a variable speed motor 91 regulated as to speed by means of a variable speed motor 91 regulated as to speed by means of a suitable rheostat or other controlling device 92 so that by rotating the motor 91 at any speed a series of pressure impulses will be created in the pipe 88, and will beat upon diaphragm 87 to create a pressure wave in the tube or pipe 83 of known frequency, the frequency being variable by varying the speed of motor 91.

At the opposite end of the pipe 83 I couple a pressure responsive device which may be constructed in the same manner as the diaphragm chamber 22 and diaphragm 23 hereinbefore described. This pressure responsive device is illustrated at 93 coupled directly to the end of the pipe 83, the diaphragm 94 of which receives the impulses transmitted through the pipe 83 to vibrate in response thereto and to move a mirror 95 in the same manner as was described with reference to the mirror 36. The mirror 95 reflects a light beam from a suitable source 96 upon a polygon of mirrors 97 revolved by means of an adjustable speed motor 97a at a speed synchronous with the speed of the motor 91 so that the amplitude and uniformity of the vibrations of the diaphragm 94 may be visibly observed.

As is well known in the art, each gaseous medium, variable as to density, temperature, etc., is resonant to pressure waves or sound waves of predetermined frequency. Thus by varying the speed of operation of the motor 61 until the pressure impulse created by the diaphragm 57 makes one round trip (or multiple thereof) to the diaphragm 64 and back to the diaphragm 57 in time to just synchronize with the next impulse created by the diaphragm 57, the pattern described by the beam of light on the mirrors 67 will show uniform amplitude, and noting the frequency of the impulses produced upon the diaphragm 57 (that is, noting the speed of the motor 61) the velocity of the sound through this particular gaseous medium may be readily determined by comparing this frequency with the frequency at which resonance is achieved at the pipe 53 with air in it.

It will therefore be observed that I have provided a method of determining the location of obstructions in wells and accurately locating and measuring the fluid level in a well without the necessity of removing any of the apparatus from the well, the entire measurement and determination being accomplished in a relatively short time.

It will be understood by those skilled in the art that the creation of pressure impulses within the well may be accomplished by decreasing the pressure in the well instead of admitting a charge of gas from the pressure tube 12 into the well. For example, if the pressure in the well is relatively high, the valve 14 in the pressure chamber may be closed and the valve 16 opened, allowing the pressure in the well to build up within the impulse chamber 12. Then by operating valve 14, allowing the pressure within the chamber 12 to rapidly discharge, a pressure impulse may be created within the well which acts in the same manner as hereinbefore described for the introduction of pressure from the tank or other source 11.

It will also be understood that if desired special constrictions may be placed in the well for future measurements of the fluid level therein to take the place of the tubing catcher 8. Such constrictions could comprise a closed cylinder of pipe surrounding and attached to one of the tubing sections when the tubing is run into the well and by noting and recording the location of such constriction, the future measurements of the fluid level by my pressure impulse method can be readily determined, employing the reflection of the wave from the restricting member in place of the reflection from a tubing catcher 8 or other restriction in the well.

While I have shown and described the preferred embodiment of my invention, I do not desire to be limited to any of the details of construction shown or described herein, except as defined in the appended claims.

I claim:

1. In an apparatus for determining the location of an obstruction in a well having therein a string of assembled tubing sections interconnected with each other by coupling collars, means communicating with said well for creating a pressure impulse in said well, echo receiving means including a pressure responsive device exposed to said well for receiving pressure impulses from the well and for measuring the lapse of time between the creation of the impulse and the arrival at said receiving means of the echo from said obstruction, and means associated with said pressure responsive device for tuning said receiving means to the frequency of echoes from the tubing collars of said tubing sections to clearly distinguish the echoes from said couplings from each other.

2. In an apparatus for determining the location of an obstruction in a well having a string of assembled tubing sections therein, means communicating with said well for creating a pressure impulse in said well, a pressure responsive device for receiving pressure impulses from the well, a pipe coupling said pressure responsive device to the well, means for adjusting the effective length of said pipe to tune said pressure responsive device to one of the harmonics of echoes of said impulse received from the coupling collars of said tubing string, and means for measuring the frequency of said tubing collar echoes and for measuring the lapse of time between the creation of said impulse and the arrival at the pressure responsive device of the echo of said impulse from said obstruction.

3. In an apparatus for determining the location of an obstruction in a well having a string of assembled tubing sections therein, means communicating with said well for creating a pressure impulse in said well, a pressure responsive device for receiving pressure impulses from the well, a pipe coupling said pressure responsive device to the well, means for adjusting the effective length of said pipe to tune said pressure responsive device to one of the harmonics of echoes of said impulse received from the coupling collars of said tubing string, and means associated with said pressure responsive device for measuring the frequency of said tubing collar echoes and for counting the same and for measuring the lapse of time between the creation of said impulse and the arrival at the pressure responsive device of the echo of said impulse from said obstruction.

4. In an apparatus for determining the location of an obstruction in a well having a string of assembled tubing sections therein, means communicating with said well for creating a pressure impulse in said well, a pressure responsive device for receiving pressure impulses from the well, a means intercoupling said pressure responsive device with the well and having such effective length as to tune said pressure responsive device to one of the harmonics of echoes of said impulse received from the coupling collars of said tubing string, and means associated with said pressure responsive device for measuring the frequency of said tubing collar echoes and for counting the same and for measuring the lapse of time between the creation of said impulse and the arrival at the pressure responsive device of the echo of the impulse from said obstruction.

5. In an apparatus for determining the location of an obstruction in a well, means communicating with said well for creating a pressure impulse in the well, a pressure responsive device including diaphragm means, means coupling said diaphragm means to said well to allow the pressure of said well to press upon one face of said diaphragm means, means communicating between said coupling means and the opposite face of said diaphragm means for equalizing the static pressure on both sides of said diaphragm means whereby said diaphragm means will move in accordance with variation in pressure within said well, and means for measuring the lapse of time between the creation of said pressure impulse and the movement of said diaphragm means by the echo of said impulse from said obstruction.

8. In an apparatus for determining the location of an obstruction in a well, means communicating with said well for creating a pressure impulse in the well, a pressure responsive device including diaphragm means, means coupling said diaphragm means to said well to allow the pressure of said well to press upon one face of said diaphragm means, means defining a restricted by-pass intercommunicating the opposite face of said diaphragm means with said coupling means to equalize the static pressure on both faces of said diaphragm means whereby said diaphragm means will move in accordance with variation in pressure within said well, and means for measuring the lapse of time between the creation of said pressure impulse and the movement of said diaphragm means by the echo of said impulse from said obstruction.

7. In a device for determining the location of an obstruction in a well, means communicating with said well for creating a pressure impulse in said well, means for receiving and translating echoes received from said obstruction including diaphragm means, coupling means intercommunicating one face of said diaphragm means with said well, means defining a pressure equalising chamber on the opposite face of said diaphragm, means defining a second chamber of greater volume communicating with said first chamber, valve means for restricting communication between said two chambers to vary the effective volume of the chamber exposed to said opposite face of said diaphragm means to control the sensitivity of response of said diaphragm means to pressure variation in said well, and means for measuring the lapse of time between the creation of said impulse and the movement of said diaphragm by the echo of said impulse from said obstruction.

8. In a device for measuring pressure waves in a fluid medium under static pressure, a diaphragm, a pressure-tight housing surrounding said diaphragm and having a window therein capable of passing light between the interior and exterior of the housing, said housing being divided by the diaphragm into two compartments, one on each side of the diaphragm, a medium entrance communicating with one compartment to directly expose one face of the diaphragm to the medium, a by-pass extending between the compartments to equalise the static pressure of the medium on opposite faces of the diaphragm, light-reflecting means associated with the diaphragm, means for directing a light beam upon said reflecting means to reflect the beam through said window, and means disposed exteriorly of said housing for receiving and translating the reflected beam.

9. In a device for measuring pressure waves in a fluid medium under static pressure, a diaphragm, a pressure-tight housing surrounding said diaphragm and having a window therein capable of passing light between the interior and exterior of the housing, said housing being divided by the diaphragm into two compartments, one on each side of the diaphragm, a medium entrance communicating with one compartment to directly expose one face of the diaphragm to the medium, a by-pass extending between the compartments to equalise the static pressure of the medium on opposite faces of the diaphragm, light-reflecting means associated with the diaphragm, means disposed exteriorly of the housing for directing a light beam through said window to strike said reflecting means and to be reflected thereby back through said window, and means disposed exteriorly of said housing for receiving and translating the reflected beam.

10. In a device for measuring pressure waves in a fluid medium under static pressure, a diaphragm, a pressure-tight housing surrounding said diaphragm and having a window therein capable of passing light between the interior and exterior of the housing, said housing being divided by the diaphragm into two compartments, one on each side of the diaphragm, a medium entrance communicating with one compartment to directly expose one face of the diaphragm to the medium, a by-pass extending between the compartments to equalise the static pressure of the medium on opposite faces of the diaphragm, light-reflecting means associated with the diaphragm, means for directing a light beam upon said reflecting means to reflect the beam through said window, means disposed exteriorly of said housing for receiving and translating the reflected beam, and means extending into said housing to adjust the position of said reflecting means to adjustably direct the reflected beam upon said receiving means.

11. In a device for measuring pressure waves in a fluid medium under static pressure, a diaphragm, a pressure-tight housing surrounding said diaphragm and having a window therein capable of passing light between the interior and exterior of the housing, said housing being divided by the diaphragm into two compartments, one on each side of the diaphragm, a medium entrance communicating with one compartment to directly expose one face of the diaphragm to the medium, a by-pass extending between the compartments to equalise the static pressure of the medium on opposite faces of the diaphragm, a light reflector associated with said diaphragm, means pivoting said reflector within the housing, means connecting said diaphragm and said reflector to move said reflector about its pivot in accordance with deflections of said diaphragm, means for projecting a beam of light upon said reflecting means to reflect said beam through said window, means disposed exteriorly of said housing for receiving and translating the reflected beam, and handle means projecting through said housing and accessible exteriorly thereof for adjusting said reflector pivot means to adjustably direct the reflected beam upon the receiving means.

12. In an apparatus for determining the location of an obstruction in a well having a string of assembled tubing sections therein, means communicating with said well for creating a pressure impulse in said well, a pressure responsive device for receiving pressure impulses from the well, means coupling said pressure responsive device to the well to expose said device to pressure variations existing in said well and having a length approximately a multiple of the length of a tubing section to tune said device to the frequency of the echoes of the impulse received from the couplings of the tubing string, and means associated with said device for recording the echoes from the tubing couplings and from said obstruction to permit counting the coupling echoes between the creation of the impulse and the echo from the unknown obstruction to determine its location.

13. In an apparatus for determining the unknown location of an obstruction in a well having a string of assembled tubing sections therein connected by couplings, means communicating

with said well for creating a pressure impulse in said well to produce echoes of said impulse from the couplings and other obstructions in said well, echo receiving and registering means coupled to said well to expose said receiving and registering means to pressure variations produced in said well by echoes from said obstructions, and means associated with said receiving and registering means to accent the registration of tubing coupling echoes.

14. In an apparatus for determining the unknown location of an obstruction in a well having a string of assembled tubing sections therein connected by couplings, means communicating with said well for creating a pressure impulse in said well to produce echoes of said impulse from couplings and other obstructions in said well, pressure responsive echo receiving and registering means coupled to said well to expose said receiving and registering means to pressure variations in said well produced by echoes from said obstructions, and interference eliminating means associated with said receiving and registering means for limiting the response of said receiving and registering means to the registration of echoes from actual obstructions in the well whereby the registered echoes of the tubing couplings may be readily distinguished from each other and from the echoes from other actual obstructions in the well.

15. In an apparatus for determining the unknown location of an obstruction in a well having a string of assembled tubing sections therein connected by couplings, means communicating with said well for creating a pressure impulse in said well to produce echoes of said impulse from the couplings and other obstructions in said well, pressure responsive echo receiving and registering means coupled to said well to expose said receiving and registering means to the pressure variations produced in said well by echoes from said obstructions, and resonance means associated with said receiving and registering means to produce therein a natural acoustical period of oscillation so related to the frequency of the echoes from the tubing couplings as to accent the registration of the tubing coupling echoes.

16. In an apparatus for determining the unknown location of an obstruction in a well having a string of assembled tubing sections therein connected by couplings, means communicating with said well for creating therein a pressure impulse to produce echoes of said impulse from the couplings and other obstructions in the well, echo receiving and registering means including a pressure responsive device, and pipe means coupling said pressure responsive device to said well to expose said device to pressure variations in the well, and means for adjusting the effective length of said pipe means to produce a natural acoustical period of oscillation of said pressure responsive device so related to the frequency of the echoes of said tubing couplings as to accent the registration of said echoes.

17. In an apparatus for determining the unknown location of an obstruction in a well having a string of assembled tubing sections therein connected by couplings, means communicating with said well for creating therein a pressure impulse to produce echoes of said impulse from the couplings and other obstructions in said well, pressure responsive echo receiving and registering means having a natural frequency of oscillation so related to the frequency of the echoes from said tubing couplings as to accent the registration of said echoes, and means interconnecting said receiving and registering means to said well to expose said receiving and registering means to pressure variations in said well.

CRANFORD P. WALKER.

PLAINTIFFS' EXHIBIT No. 2

Walker Reissue Patent No. 21,383

[Endorsed]: Filed Oct. 6, 1943.

600

March 5, 1940. C. P. WALKER Re. 21,383

METHOD OF DETERMINING FLUID DENSITY, FLUID PRESSURE, AND THE PRODUCTION CAPACITY OF OIL WELLS

Original Filed Oct. 26, 1937

FIG. 1.

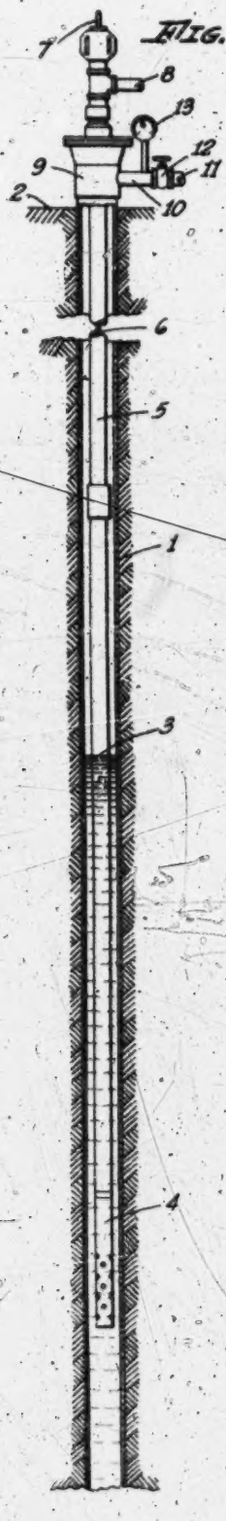


FIG. 2.

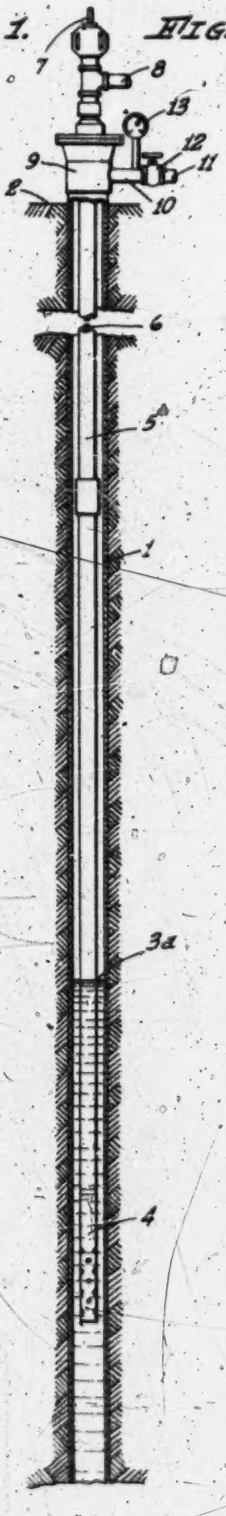
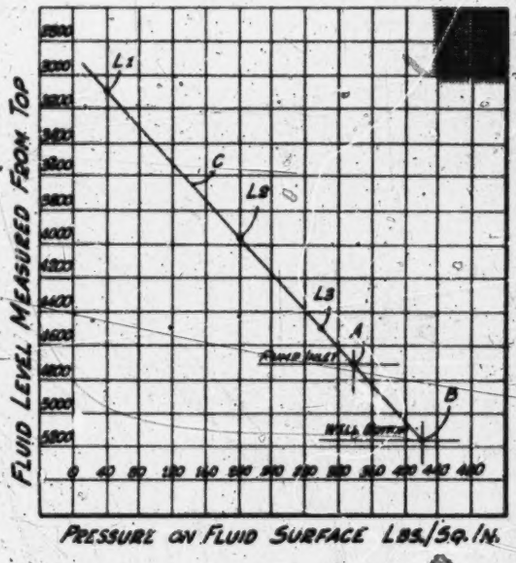


FIG. 3.



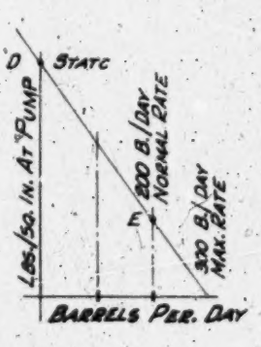


FIG. 4.

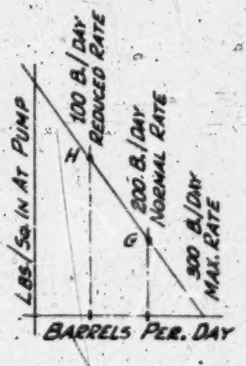


FIG. 5.

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Re. 21,383

UNITED STATES PATENT OFFICE

21,383.

METHOD OF DETERMINING FLUID DENSITY, FLUID PRESSURE, AND THE PRODUCTION CAPACITY OF OIL WELLS

Cranford P. Walker, San Marino, Calif.

Original No. 2,161,733, dated June 6, 1939, Serial No. 268,895, April 19, 1939, which is a continuation of Serial No. 171,170, October 26, 1937. Application for reissue December 4, 1939, Serial No. 307,551

11 Claims. (Cl. 73—51)

My invention relates to methods of determining the fluid density, fluid pressure and potential production capacity of oil wells and has particular reference to methods of determining the most desirable character of pumping equipment and manner of operating the same to permit an efficient production of oil from a given well.

This application is a continuation of my copending application Serial No. 171,170, filed October 26, 1937.

It is the common practice in oil well production activity to permit an oil well to produce as a flowing well, that is, to permit the oil to flow out at the ground surface due to the pressure in the oil formations, until the production rate reaches a considerably low value or ceases, after which gas lifting is usually attempted and continued until the production rate with gas lifting reaches a relatively low value or the production entirely ceases. At this time, and in some instances prior to any attempt to gas lift the oil, mechanical pumping devices are usually installed to lift the oil by mechanical means to the surface, these pumps usually comprising a pump barrel located at a considerable depth in the well, usually 50 to 150 feet below the surface of the well fluid in the well while it is producing, plungers or other reciprocating devices being employed in the barrel and operated from the ground surface by means of sucker rods.

Usually the selection of the size and character of the pumping equipment is determined by the production of the well during its flowing or gas lifting life by estimating from this production the type or character of pump which appears to be most suitable. In many fields, however, the type, size and character of the pump installed is usually one determined as "standard" for that particular type of well in the particular field. In other words it is one having the same dimensions as pumps in other wells producing from the same horizon. Frequently, such well receives no further attention until the field as a whole has declined to a point where it becomes necessary to increase the production from the wells, as for example, by the encroachment of water, necessitating the lifting of greater quantities of liquid in order to obtain the desired amount of oil. When this condition occurs, it is customary to increase the capacity of the pumping equipment.

Also, the production from a given well may be believed to be less than the character of the well and the character of the pumping equipment employed should indicate, as for example, the pump may be operating at a relatively low volumetric efficiency. As is well understood, the column of well fluid extending up into the well bore is a mixture of dense oil and gas entrained therewith and the maximum volumetric efficiency of the conventional pumping equipment is attained when the pump inlet is located along this column at such place as will permit a maximum amount of dense liquid to flow into the pump upon each stroke. Thus if the pressure in the column at any point below the surface of the column can be determined, the pump inlet may be so properly located as to allow it to take in a minimum quantity of gas upon each stroke. At this point it should be noted that wherever in the following description the expression "fluid", "fluid surface", "fluid level", are used, the word "fluid" is intended to refer to the natural well fluid which comprises a mechanical mixture of dense liquid, (either oil or oil and water) with such quantities of gas entrained therein as may be present in the particular well under consideration.

In order to determine whether or not any change in the size, character, operating characteristics or location of the pumping apparatus should be made, it is desirable that the location of the fluid surface, the character of the fluid in the well, its density and the fluid pressure exerted at any given point below the surface of the fluid and the maximum potential production capacity of the well should be determined. For example, if the pumps in a particular field are operating at good volumetric efficiency, much can be determined from the quantity of oil produced and the volumetric displacement per stroke of the pump, and if the pumps are operating at their maximum capacity, the fact that the fluid level is at a considerable distance above the pump inlet may indicate that the operator is justified in making a change in the size or character of the pumping equipment. Again, if the volumetric efficiency of the pump is found to be low, as for example, when the pump appears to be taking in a comparatively large quantity of gas upon each stroke of the pump, the operator should know whether or not the inlet of the pump is located at a point too near the fluid surface to that he may determine how far below the fluid surface he should lower the pump in order to allow it to receive dense fluid for the full stroke.

Frequently in wells where the quantity of gas produced by the well is relatively small, an increased production of the pump may be ob-

tained by raising the pump to a point nearer the fluid surface so that a better separation of the gas takes place prior to the entry of the fluid into the pump, while if the well is making a large quantity of gas, it may be better to lower the pump to a point below where free gas enters the well bore, if this is possible, so that upon each stroke of the pump, dense liquid will be picked up. However, in many instances, it is dangerous to lower the pump too close to the bottom as sand is likely to be pumped into and foul the pump.

In wells where the fluid level is so low that the pump is not completely submerged and hence does not receive a full cylinder, or barrel of fluid upon each stroke, a pounding at the pump is created which may be heard or determined at the ground surface. This same character of pounding, however, may be produced by the pump even though the fluid surface is at a considerable distance above the pump inlet, occasioned by the inflow into the pump of large quantities of free gas. Hence, simple tests to determine the fluid level relative to the pump inlet will show which of these two conditions exists but will not produce the desired information to the operator as to the desirable character or location of the pumping mechanism.

If, however, the fluid pressure at different levels below the surface of the fluid is determined, this information may be employed to determine the most desirable location of the pump and whether or not a change should be made in the size, operating characteristics or character of the pumping equipment employed in a given well to produce an increased or maximum production from the well.

The determination of the fluid pressure at different points below the surface of the well fluid may be determined by instruments known as pressure recorders, which must be either attached to the pump or lowered into the well to the desired level, or must be lowered into the well on wires, cables or other supporting devices and left at the desired levels for a predetermined length of time necessary to permit the recorders to make a chart or record of the pressures encountered. All of these methods, however, required the stopping of the pumps and the stopping of production while the test is being made and further required the removal of the pumps and sucker rods and sometimes the tubing and other apparatus from the well in order to insert the pressure recorders or pressure measuring devices, which entailed considerable labor and time and held up the production of the well for a considerable period of time.

It is therefore an object of my invention to provide methods for determining the fluid pressure at any given point below the surface of the column of well fluid which extends up into the space between the casing and the pump tubing (known as the "standing column"), determining the density of the fluid in such column and the production index of the well without interrupting or interfering with the production of the well by the usual pumping apparatus employed therein.

Another object of my invention is to provide a ready means for determining the fluid pressure at any level below the surface of the standing column of fluid in the well and for determining the density of the well fluid in any particular well without necessitating the removal or replacement of any of the usual pumping apparatus, flow tubes, sucker rods or other mechanism found in a well being produced by a mechanical pump.

Another object of my invention is to provide information to aid in the determining of the proper location of the pump in an oil well to achieve the maximum volumetric efficiency of the pump in handling the particular character of well fluid found in the particular well.

Another object of my invention is to provide a ready method for determining the potential production capacity of an oil well with a minimum of expense, delay or interruption of the production activities of the well.

Another object of my invention is to provide a method of determining the density of the fluid in a well by measuring the amount of recession of the level of the fluid surface under two or more conditions of pressure upon the fluid surface and computing from the facts thus obtained the density of the fluid in the well. Fluid densities in producing wells range all the way from less than .04 pound per square inch to over .4 pound per square inch per foot of fluid in the well. Therefore, a simple fluid level determination without a density or pressure determination gives very little information.

Another object of my invention is to provide a ready method for determining the potential production capacity of a well by measuring the pressure at the pump inlet under two conditions of operation of the pump and computing therefrom the maximum potential production obtainable from the well.

Another object of my invention is to provide a ready method for determining the potential production capacity of a well by determining the fluid pressure at some point below the fluid surface in the well, either at the pump inlet or any other location, under two conditions of production from the well (one of which may be zero production), and by comparing the pressures so determined with the production rates, determining the maximum potential production obtainable from the well.

Other objects of my invention will be apparent from a study of the following specification read in connection with the accompanying drawing, wherein

Fig. 1 is a diagrammatic, cross-sectional view of a typical oil well, illustrating the level of the fluid surface as being located a considerable distance above the inlet of the pumping apparatus employed;

Fig. 2 is a view similar to Fig. 1 but illustrating the effect on the fluid surface of gas pressure allowed to build up in the casing;

Fig. 3 is a diagrammatic view illustrating a chart or graph which may be employed in the practice of my method for the computation of fluid density and pressures at different locations or levels within the well;

Fig. 4 is a diagrammatic view illustrating a chart or graph which may be employed to compute the maximum potential capacity of a well from a comparison of the pressure at the pump while it is idle with the pressure at the pump while it is operating normally; and

Fig. 5 is a view similar to Fig. 4 illustrating the manner in which a more accurate computation of the potential capacity of a well may be obtained by comparing the pressure at the pump under two production rates of the pumping apparatus.

Referring to the drawing, I have illustrated

Fig. 1 a typical oil well which includes a casg 1 extending down through the well bore from e ground surface 2 into the oil producing sands, e oil flowing from the sands or oil formation to the casing and rising in the casing to some vel indicated at 3. Pumping apparatus emloyed to remove the oil from the well usually ncludes a suitable pump 4 located upon tubing ring 5, constituting the flow tubing through hich the oil is raised to the ground surface, ne pump 4 including usually some reciprocatng mechanism operated by reciprocal movements of a string of sucker rods 6 extending own through the tubing 5 and connected to reciprocating power apparatus at the ground surface, as indicated at 7. The flow tubing 5 is provided with an outlet 8 communicating with a uitable oil line through which the oil pumped rom the well is conveyed to any desired location.

The casing 1 is closed at its upper end as indicated at 9, an outlet 10 being provided communicating with the casing 1 to permit gas escaping from the oil to pass into a suitable gas line 11, a control valve 12 being usually provided to control the flow of gas into the gas line.

By properly selecting the size, the stroke and the speed of the pump 4, the pump may be made to remove the oil from the well at approximately the same rate at which the oil flows into the well from the surrounding formation, and if so selected, the well will be operated at its maximum capacity. However, oil coming from the formation contains relatively large quantities of gas which, due to the pressure of the oil, cannot readily escape and is drawn into the pump with the oil, thereby reducing the liquid volumetric efficiency of the pump.

I have discovered a ready means for ascertaining the pressure existing at the pump entrance or at any other point below the surface of the standing column of well fluid in any given well without requiring the removal of the pump or any of its parts, and I have also discovered a ready method for determining the density of the well fluid, the information so obtained being used to select the location of the pump at the most desirable level and for use in determining the production capacity of the well.

To obtain the information required, I measure or determine the stable location of the fluid surface of the "standing column" of fluid within the well when the pump is operating at its normal production capacity and with the pressure of gas within the casing at the usual or normal value maintained during the usual or normal pumping operations at the well. The expression "standing column" as used herein is intended to mean the column of well fluid which stands in the well as distinguished from the pumped liquid column which is being lifted to the ground surface by the pump, such standing column being known in the oil industry as the "dead" fluid column, and with the usual type of pumping apparatus this standing column lies in the annular space between the tubing 5 and the casing 1.

This location of the fluid level may be readily accomplished by employing the methods and apparatus disclosed in United States Letters Patent No. 2,047,974, issued to Harold T. Wyatt and Paul E. Lehr, July 21, 1936, and in United States Letters Patent No. 2,156,519, issued to me on May 2, 1939, and in my copending application Serial No. 164,534, filed September 18, 1937. While the methods and apparatus are completely disclosed in the said patents and application, the method may be stated briefly as including the introduction into the annular space between the tubing 5 and the well casing of a sudden change in pressure in the well casing and measuring the length of time elapsing between the production of this pressure impulse and the return to the ground surface of the echo thereof from the surface of the fluid. Noting the distance from the ground surface of the fluid level under these conditions and noting the pressure of gas at the casing head, as by means of a pressure gage 13, the pressure on the fluid surface may be computed as follows: To the casing head pressure is added the effect of pressure on the fluid surface exerted by the weight of the column of gas between the fluid surface and the casing head. A gravity test may be made of the gas at the casing head which will determine the pressure exerted by each foot or hundred feet of height of the gas column. This information may be computed by the following formula which is by Dice:

$$\text{Log}_{10} Pb = \frac{SD}{122.827T} + \text{Log}_{10} Pt$$

Where

Pb=Lbs./sq. in. absolute at bottom of gas column.
Pt=Lbs./sq. in. absolute at top of gas column.
S=Specific gravity of the gas (air is considered 1).
D=Depth from casing head to fluid surface.
T=Mean temp. of the gas column in degrees R. absolute.

This information may then be plotted upon a graph or chart as illustrated in Fig. 3 in which the conditions existing in the particular well under measurement are assumed to be such that with a pressure of 36 pounds per square inch at the casing head, the fluid surface is found to lie at 3100 feet below the casing head. The specific gravity of the gas in this instance may be found to be such that the effect will be to produce 4 pounds per square inch pressure on the fluid surface. Thus, the addition of 36 pounds and 4 pounds produces a total pressure on the fluid surface of 40 pounds per square inch. By arranging the chart shown in Fig. 3 with the ordinates representing the fluid level measured from the ground surface and the abscissae representing pressure on the fluid surface in pounds per square inch, the point L1 determined from the preceding formula may be plotted on the chart shown in Fig. 3.

Now the valve 12 is closed or a suitable pressure regulator is placed in the gas line 11 and the pressure within the casing is allowed to build up to any predetermined value. As the pressure builds up, the fluid level 3 tends to recede, the pump drawing down the fluid column until a stable condition of production and fluid level is reached under the new gas pressure. By continuing the operations of the pump during the building up of this pressure, preferably for a period substantially equal to three times the length of time required for the pump to remove the column of fluid between the original fluid level and a new fluid level to which the pressure depresses the fluid surface, represented at 3a (Fig. 2), a stable condition will be achieved at which the fluid level will become constant and the production by the pump will be approximately the same as before the pressure was allowed to build up in the casing. When this stable condition is reached, a second measurement of the fluid level is obtained by the level measuring methods and apparatus hereinbefore described.

Having determined the new location of the fluid surface, the pressure exerted thereon may now be calculated as follows: Assuming that the casing head pressure in this instance was adjusted to 170 pounds, to this should be added the pressure due to the weight of the column of gas above the new fluid level. The determination of the effect of the weight of the column of gas upon the fluid level may be obtained either by calculation or may be plotted out and obtained from suitable charts prepared for this purpose. In this instance, it may be assumed that the pressure due to the gas column is 30 pounds per square inch, making a total of 200 pounds per square inch on the fluid surface. Now, assuming that the level to which the standing column of fluid has receded is 3966 feet from the top of the well, the new point L2 on the chart shown in Fig. 3 representing the new level and the pressure on the fluid surface may be placed upon the chart.

From an exhaustive series of actual tests I have discovered that in any given well which is being produced by a mechanical pump and where the cross sectional area of the standing fluid column is constant, there is a constant relation between a change in the pressure upon the fluid surface and the corresponding change in the location of the stable fluid surface for any given rate of production. This result follows from the fact, as I have discovered, that even though large quantities of gas bubbles are usually flowing vertically through the fluid column in a pumping well, the density of the gas and oil mixture in the column is constant throughout the height of the column. This is contrary to the usual concept of the fluid density in producing oil wells as heretofore it has been possible to explore, usually with a pressure recorder, the density of the fluid in flowing wells only. These measurements are usually made in the flowing column of fluid where, on account of gas breaking out of the liquid as it flows up to regions of lower pressure, the fluid density is found to increase with the depth to which the pressure recorder is run in the column. Under equilibrium conditions in wells being produced by mechanical pumps there is evidently very little gas liberated from the liquid in the standing column, therefore the volume of gas which enters the column at the bottom is practically the same as that given off at the top. The constant density phenomena which I have discovered appears to be due to the fact that the size of the gas bubbles decreases, and their density increases with their depth in the fluid column. They therefore travel much slower near the bottom than they do near the top of the fluid column where they are large and light. At the bottom therefore there are many small heavy gas bubbles traveling close together vertically upward at a slow rate whereas as these same bubbles approach the top of the column they become very large and light and travel at a high speed and are farther apart. The relations of bubble size, weight and velocity at different levels in the fluid column are evidently such that the proportions of gas and liquid are constant throughout the height of the column and the density does not change.

It follows therefore that an increase in pressure on the surface of the fluid column will cause the column to recede through a distance directly proportional to the increase in pressure. Hence a line drawn on the chart shown in Fig. 3 intersecting the points L1 and L2 will truly represent the fluid level at any of the pressures which may be placed upon the column. Thus by merely extending the line C downwardly on the chart until it crosses the ordinate representing the location of the pump inlet indicated on the chart as A, a direct reading may be made from the chart of the pressure on the fluid surface which would be required to cause the surface of the column to recede to the pump inlet. On the chart this is represented as 336 pounds per square inch, which is the pressure exerted by the well fluid in that particular well at the pump entrance for the normal casing pressure and normal rate of production, assuming that the rate of production was normal during these tests.

The actual pressure in the column of fluid at the pump inlet may, however, be calculated from the information received by the two fluid level tests described above. That is, by subtracting the original fluid level from the new fluid level, the total difference in level will be found, in this instance 866 feet. Then by subtracting the original pressure on the fluid surface from the new pressure on the fluid surface, a difference of 160 pounds per square inch is found to have been necessary to cause the fluid column to recede 866 feet. By dividing the difference in fluid pressure by the difference in surface level, the density of the mixture of oil and gas in the well (that is, the pressure exerted by this mixture per unit of height of the column of the mixture) may be found. In this instance, the column receded a distance between 3100 feet and 3966 feet, or a total distance of 866 feet, while the pressure difference is 160 pounds. The density of the fluid in the column is such therefore as to exert 0.185 pound per square inch per foot of height of the column.

Hence, knowing the pressure on the fluid surface at any level thereof and knowing the distance below this surface at which the pump inlet is located, a direct calculation of the fluid pressure at the pump inlet may be obtained by the following formulae:

The pressure at any point below the normal surface level in a well at which the level can be maintained by means of gas pressure in the casing is

$$PL1=Pc1+Pg1 \text{ and } PL2=Pc2+Pg2$$

The density of the fluid for the rate of production during the tests is

$$D=\frac{PL2-PL1}{L2-L1}=\text{density of the fluid in lbs. per sq. in. per foot of fluid.}$$

The pressure at the pump is

$$Pa=D(La-L2)+PL2$$

Where

Pc1=gage casing pressure to maintain fluid at level L1.
Pc2=gage casing pressure to maintain fluid at level L2.
Pg1=pressure exerted upon fluid surface by weight of gas above it at level L1.
Pg2=ditto for level L2.
PL1=pressure on the fluid surface at level L1.
PL2=pressure on the fluid surface at level L2.
L1=fluid level corresponding to Pc1.
L2=fluid level corresponding to Pc2.
La=pump location in feet from ground surface.
Pa=pressure at the pump.

In the example shown in Fig. 3, assuming the inlet to the pump is located at the 4700 foot level, the pressure of the fluid at this point would be equal to the sum of the gas pressure at the

casing head for level L2, the pressure exerted by the column of gas above the fluid surface corresponding to this level and the pressure exerted by the column of fluid above the pump inlet. In this instance, the pressure at the casing head is assumed to be 170 pounds per square inch, the effect of the column of gas at this pressure with the fluid level at 3966 feet from the surface being 30 pounds per square inch and the effect of the column of fluid above the pump inlet being 734 feet at 185 pounds per square inch per foot, or 135.5 pounds per square inch exerted by the column of fluid, the result being 335.5 pounds per square inch pressure at the pump entrance. This result is clearly illustrated in Fig. 3 by the point A, the point A being located at 335.5 mark on the abscissae of the chart.

If desired, an estimation of the bottom hole pressure may also be made by continuing the line C downwardly on the chart to intersect the ordinate representing the bottom of the well, such point being indicated at B, or the pressure at any other level in the well below the surface of the well fluid for the rate of production at which the tests were made may be located along the line C. I have discovered that in wells employing mechanical pumps for any given production rate by the pump, the density of the oil-and-gas mixture is constant throughout the height of the standing column of fluid in the annular space between the tubing and casing so that the line C once established continues as a straight line, the effect in pressure per unit of height of the column being constant throughout the height of the column.

Knowing the density of the well fluid and the pressure exerted at the pump inlet, the operator of any particular well may determine whether or not it is practicable to increase the amount of liquid being produced. If the volumetric efficiency of the pump is low and the tests indicate considerable pressure at the pump, he may raise the pump to a level indicated upon the line C at which better separation of gas will usually occur prior to entry of liquid into the pump.

The utilization of the information obtained by the foregoing method will also accurately produce the information of the maximum potential production of the well as by comparing the pressure of the fluid at the pump under two or more different operating conditions of the pump. For example, the static fluid pressure at the pump when the pump is not operating may be measured and compared with the fluid pressure at the pump when the pump is operating at its normal rate of production or at any other rate of production, a comparison of the two values so obtained will produce a constant, indicating the ratio between the rates of production and pressure at the pump inlet, so that by employing this constant at a theoretical zero pump inlet pressure (which would represent the fluid being removed from the well at the rate it flows into the well from the formation) the maximum potential capacity of the well may be found.

Employing the method of determining fluid pressure at the pump hereinbefore described, the static pressure may be readily obtained without necessitating the use of pressure recorders or other devices requiring the removal of or alteration of any of the pumping mechanism and the measurement may be made in wells which have been shut down as readily as in wells which are actively producing.

To obtain the fluid pressure at any point at or below the fluid surface when the pump is not producing fluid, the casing should be closed in and the gas escaping from the well fluid should be allowed to build up pressure in the casing until a stable condition is reached, that is, a point is reached at which no more gas is made by the well (no more gas escapes from the well fluid). When this point is reached, the remaining well fluid in the well may be considered as dense liquid.

Now, by determining the height of the fluid surface under these conditions by my method, the pressure on the fluid surface may be readily determined and by adding thereto the effect of the weight of the column of fluid above any given level, the fluid pressure at that level may be found. This information alone is extremely useful to the operators of producing wells.

The information thus obtained may be plotted on a graph or chart such as that shown in Fig. 4, wherein the ordinates represent fluid pressure at the pump inlet in pounds per square inch and the abscissae represent rate of production of oil from the particular well under consideration, and the static pressure may be plotted at zero production, as indicated by the point D in Fig. 4.

The casing pressure may now be reduced and the pump started and allowed to assume a predetermined rate of production, preferably its normal rate. Assuming this rate is 200 barrels of oil per day, a new determination of the fluid pressure at the pump is made at this rate of production. That is, the pump is started and allowed to operate until the fluid level in the well reaches a stable condition. The location of the fluid level and the pressure in pounds per square inch at the pump inlet under these conditions are determined by the method hereinbefore described and the fluid pressure at the pump is plotted against the production rate on the chart shown in Fig. 4. Assuming that this new pressure at 200 barrels per day is found to be at the point indicated in Fig. 4 at E, a straight line drawn between the points D and E will intersect the zero pressure ordinate at a point representing the maximum potential capacity of the well. In the diagram shown in Fig. 4, this maximum potential production capacity is found to be 300 barrels per day. In other words, if a pump of sufficient capacity is installed in this well and operated in such manner as to remove 300 barrels per day, the oil will be removed at the same rate at which it flows into the well from the formation.

A more accurate determination of the maximum potential production capacity of the well may be made by comparing the fluid pressure at the pump under two different actual producing conditions of the pump, such as by measuring the fluid pressure at the pump when the pump is operating at one production rate, for example, its normal rate, and then changing the rate of production of the pump as by slowing the pump down or changing the stroke of the pump and plotting the relation between the new production rate and the fluid pressure measured by my method, as set forth herein, it will be found that a line intersecting these two points will also represent the relation between production rate and fluid pressure at the pump at any rate of the production by the pump.

As shown in Fig. 5, the normal production rate of 200 barrels per day plotted against the fluid pressure at the pump in pounds per square inch

may be represented upon the chart by the point G while at a reduced rate of production at the pump, say to 100 barrels per day, it will be found that the fluid pressure at the pump is increased so that by determining the fluid pressure under these conditions, the relation between the reduced production rate and the fluid pressure at the pump may be plotted by the point H. A straight line interconnecting the points H and G will intersect the zero pressure ordinate at a point therealong, indicating a maximum possible production of 300 barrels per day. In making such determinations, however, it is desirable that the rate of production of the pump be reduced to at least two-thirds of its normal production rate and preferably to 50% of its normal production rate in order to obtain substantially widely separated points H and G.

Again, it will be noted that all of the necessary calculations to determine the maximum production possible of the well may be made without interrupting the normal production conditions at the well and without requiring the laborious efforts of removing and replacing any of the pump mechanisms.

It will therefore be observed that I have provided a ready method for determining the density of the fluid in any particular well and also for the determination of the fluid pressure at the pump without requiring the removal or alteration of any of the usual mechanism found in the well. It will also be noted that I have provided a ready method for graphically determining the fluid pressure at the pump by first determining the amount of recession of the fluid level due to changes in gas pressure exerted upon the fluid surface and plotting this information upon a graph or chart and extending a straight line intersecting the two or more points so located to a point on the chart representing the level of the pump inlet.

It will also be noted that I have devised a ready means for utilizing the information obtained with respect to fluid levels and gas pressures at the casing head for mathematically determining the fluid pressure at the pump and also for utilizing this information to determine accurately the potential production of any well measured. It should also be noted that all of the measurements necessary to provide for the computations and calculations explained herein may be accomplished without interrupting the operation of the pump except for the measurement of the static pressure as described herein.

While I have shown and described the preferred embodiment of my invention, I do not desire to be limited to any of the details illustrated or described herein, except as defined in the appended claims.

I claim:

1. The method of determining the density of the standing column of fluid in a well, which comprises measuring the stable level of the fluid column under one condition of gas pressure, changing the pressure of gas within the well to move the surface of the fluid column to a new stable level, measuring the new stable level and dividing the change in pressure on the fluid surface required to achieve the new level by the difference in height between the two levels.

2. The method of determining the density of fluid in a well having a casing and a pump suspended therein on tubing and without requiring removal of pump parts, which consists in determining the fluid level in the annular space between the pump tubing and the casing under one condition of pressure, changing the pressure of the gas within the well to move the fluid surface to a new stable level, measuring the new level and dividing the change in pressure on the fluid surface required to achieve the new level by the difference between the two levels.

3. The method of determining the density of the standing column of fluid in a well having a casing and a pump suspended therein, which consists in measuring the level of the standing column of fluid in the well while the pump therein is operated at a given rate of production and under a known condition of gas pressure on the surface of the fluid column, changing the gas pressure on the fluid column, continuing the operation of the pump at the same production rate until the level of the standing column becomes stable at a new location, measuring the new level and comparing the difference in the pressures exerted on the fluid surface at the two levels within the difference in height of the two levels.

4. The method of determining the density of the standing column of fluid in a well having a casing and a pump suspended therein, which consists in measuring the stable level of the surface of the standing column of fluid under one condition of pressure of gas released by the well, measuring the pressure on said fluid surface under said one condition of gas pressure, regulating the flow of gas from the well to increase the pressure of said gas to a different value to depress the surface of said standing column to a new stable level, measuring the new level, measuring the pressure on the fluid surface at the new level, and comparing the difference in the pressures exerted upon the fluid surface under the two conditions of gas pressure with the difference in height of the levels of the fluid surface under the two pressure conditions.

5. The method of determining the density of the standing column of fluid in an oil well having a casing and a mechanical pump suspended therein upon pump tubing and without requiring the removal of pump parts, which consists in the steps of operating the pump under one stable condition of gas pressure in the casing until the fluid level becomes stable, measuring the distance between the casing head and the surface of the fluid under this stable condition, altering the casing pressure to a new condition, operating the pump at the same rate of production under the new condition of gas pressure to again stabilize the fluid level, measuring the distance between the casing head and the new level of the fluid surface under said new stable condition, and measuring the casing head pressures under the two stable conditions, whereby the pressure exerted by the fluid per unit of height of the fluid is represented by comparing the difference in height of the fluid surface levels and the difference between the pressures on the fluid surface required to maintain the fluid surface at the two levels.

6. In a well having a casing and a pump suspended therein, the method of determining the unknown pressure exerted in the standing column of fluid in the well at any desired level below the normal surface of said column and without requiring the removal of any of the pump parts, which comprises measuring the actual stable level of the fluid column under one known condition of gas pressure in the casing, determining the pressure on the fluid surface at that level,

changing the pressure of gas in the well to move the surface of said column to a new actual stable level, measuring the new level of the fluid surface, determining the pressure on the fluid surface at the new level, determining the density of the fluid by dividing the change in pressure on the fluid surface required to achieve the new level by the difference in height of the two levels, and computing the unknown pressure at the desired level by adding to the pressure on the fluid surface at either of the levels the effect in pressure of the column of fluid of the density so determined between the selected actual level and the desired level.

7. In a well having a casing and a pump suspended therein, the method of determining the unknown pressure exerted in the standing column of fluid at any desired level below the normal surface of said column while the pump is operating to remove fluid from the well, which comprises measuring the actual stable level of the fluid under one known condition of gas pressure in the well by sonic sounding method, determining the pressure on the fluid surface at that level, changing the pressure of the gas in the well to move the surface of the column to a new actual level, continuing to operate the pump at the same production rate as for the first condition of gas pressure in the well until the fluid level again becomes stable, measuring the new stable level and determining the pressure upon the fluid surface at this new level, determining the pressure exerted per unit of height of the fluid column by dividing the change in gas pressure on the fluid surface required to effect the change in the fluid level by the difference in height of the two levels, and computing the unknown pressure at the desired level by adding to the gas pressure upon the fluid surface at either of the actual levels the effect in pressure of the fluid column between the selected actual level and the desired level.

8. The method of determining the potential production capacity of a well having a casing and a pump suspended therein, which comprises measuring the stable level of the surface of the standing column of fluid in the well at one known rate of production and under one known condition of gas pressure in the well, determining the pressure on the surface of the fluid column at that level, changing the gas pressure in the well to move the surface of the fluid column to a new stable level, measuring the level of the fluid surface under the new gas pressure condition and determining the pressure on the fluid surface at the new level, dividing the change in pressure on the fluid surface by the difference in height between the two levels to thereby determine the density of the fluid in the column at that rate of production, determining the pressure at some predetermined desired point below the normal fluid surface for that rate of production by adding to the pressure on the fluid surface for either of the measured levels the effect in pressure of the column of fluid between that level and the predetermined desired point, then changing the rate of production by the pump and repeating the fluid level change and gas pressure determinations to determine the density of the fluid in the column and the pressure of the fluid at the said predetermined desired point for the new rate of production and then dividing the difference in the two production rates by the difference in the corresponding fluid pressures at the desired point and using the ratio thus found to determine the maximum rate at which the well is capable of being produced.

9. The method of ascertaining the pressure exerted by the well fluid at any point below the normal surface thereof, which comprises: determining the location of the fluid surface under one condition of pressure of gas on the surface, determining said gas pressure under said one condition, changing the gas pressure to move the fluid surface to a new stable level, determining the new gas pressure on the fluid surface, determining the location of the new surface level and comparing the difference in said gas pressures with the corresponding change in height of the surface level to determine the relation between them, whereby the gas pressure on the fluid surface which is required to maintain the fluid surface at any selected point may be ascertained and which pressure represents the normal pressure exerted in the fluid at said point.

10. The method of ascertaining the pressure exerted by the well fluid at any point below the surface thereof while a mechanical pump is operating in that well, which comprises: determining the stable location of the fluid surface under one condition of gas pressure in the casing of the well; determining the gas pressure on the fluid surface at that level; changing the pressure of gas in the casing to move the fluid surface to a new stable level; determining the new location of the fluid surface; determining the gas pressure on the surface at the new level; and comparing the difference between the pressures on the surface with the corresponding change in the height of the fluid surface to thereby determine the relation between changes in pressure on the fluid surface and the corresponding changes in the location of said fluid surface from which relation the pressure at any selected point may be ascertained.

11. The method of determining the potential production capacity of a well having a casing and a pump suspended therein, which comprises: determining the pressure exerted by the well fluid at some selected point below the normal surface thereof under one known rate of production, by determining the location of the fluid surface under one condition of gas pressure on the surface, determining the gas pressure on the fluid surface under said one condition, changing the gas pressure to move the fluid surface to a new stable level under the same production rate, determining the new gas pressure on the fluid surface, determining the location of the new surface level, comparing the difference in said gas pressures with the corresponding change in height of the surface level, to thereby ascertain the pressure exerted at said selected point under said one rate of production; changing the rate of production from said well; repeating the steps of determining the location of the fluid surface at two stable levels and the gas pressures on said surface to maintain said levels under the new production rate to ascertain the pressure exerted at the same selected point; and comparing the difference in the production rates with the corresponding difference in pressures at said selected point to determine their relation from which the maximum rate of production from the well may be determined.

CRANFORD P. WALKER.

PLAINTIFFS' EXHIBIT No. 3

Patent No. 2,209,944 July 30, 1940

To

C. P. Walker

For

"Method of Measuring Location of Obstructions in Deep Wells."

[Endorsed]: Filed Oct. 6, 1942.

July 30, 1940. C. P. WALKER 2,209,944

METHOD OF MEASURING LOCATION OF OBSTRUCTIONS IN DEEP WELLS

Original Filed Sept. 7, 1937

FIG. 1.

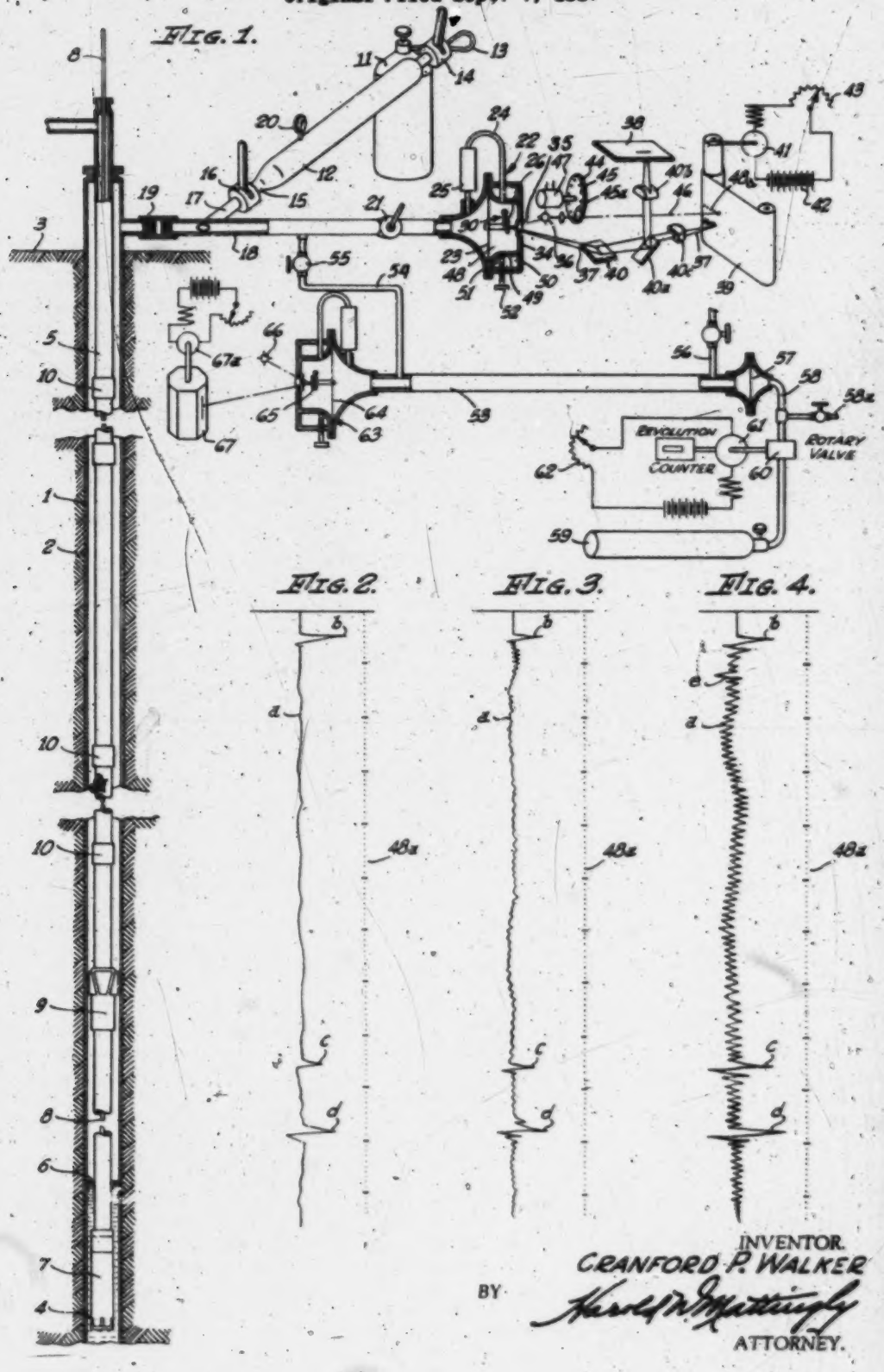

FIG. 2.

FIG. 3.

FIG. 4.

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UNITED STATES PATENT OFFICE

2,209,944

METHOD OF MEASURING LOCATION OF OBSTRUCTIONS IN DEEP WELLS

Cranford P. Walker, San Marino, Calif.

Division of application September 7, 1937, Serial No. 162,699, now Patent No. 2,156,519, dated May 2, 1939. Continuation of application April 29, 1939, Serial No. 270,865. Divided and this application September 25, 1939, Serial No. 296,781

9 Claims. (Cl. 181—0.5)

invention relates to a method of measur- e location of obstructions in deep wells s oil wells and has particular reference hods for determining the location below ound surface of the liquid level in the well, location of tools, pipe sections, couplings r devices which constrict the well bore.

is a division of my copending application No. 162,699, filed September 7, 1937, which ued as United States Letters Patent No. 19 on May 2, 1939, and a continuation of plication Serial No. 270,865, filed April 29, wherein is described and claimed apparatus easuring the location of obstructions and for producing pressure wave echoes in the echoes from certain of the obstruc- are accented so as to make them more distinguishable.

ng the active life of an oil well it is de- from time to time to determine the loca- the fluid level within the well for the pur- determining the type of pumping appa- nost desirable to be used, determining the flow of oil into the well, and for making determinations desirable in the most effi- peration of the well.

methods of determining the location of the evel or the location of other obstructions well have been generally of two types, one ch measuring apparatus has been lowered he ground surface to determine by the of cable or the line extended into the well pth or location of the fluid or other ob- ons encountered by the instrument as it red. Among devices to be lowered into the also included a pressure recorder which lowered into the well on a wire, the length ich is metered to determine the static e in the well at different levels, a varia- which includes a pressure recorder with driven chart lowered on the bottom of mp to obtain a record of the operating es or levels of the fluid. A further varia- that of lowering a bailer upon a rope and measuring the wetted surface of the rope eatedly lowering the bailer until it brings d, measuring the length of the line upon ccurrence. The other method is that of ing sound waves in the well and noting psed time between the introduction of the and its return as an echo from the sur- the liquid or other obstruction encoun-

her of these methods is satisfactory, the aving the disadvantage of requiring the removal of oil flow tubing, sucker rods and other apparatus normally disposed in the well prior to the time the instrument is inserted in and lowered into the well, requiring a considerable length of time both for the removal of such apparatus, the reinsertion of the apparatus, and the making of the actual measurement. The other method is unsatisfactory primarily because of the relatively low intensity or energy which can be employed in the sound wave so that the echo received back is of such low energy as to prevent its accurate detection and, further, little or no distinction is made by reason of such low energy between various types of obstructions encountered by sound waves.

A third method, namely, that of introducing a shock of relatively high intensity into the well, creating thereby a pressure wave which travels through the well, and measuring the elapsed time between the introduction thereof and the echo thereof, to give an indication of the depth of the fluid level and other obstructions, has been introduced, one form being that of creating a relatively loud noise such as a shot or an explosion in the well, another form being illustrated and described in United States Letters Patent No. 2,047,974, issued to Harold J. Wyatt and Paul E. Lehr on July 21, 1936. This latter method has the desirable characteristic of permitting the employment of relatively high intensity in the wave or impulse produced in the well and it is an object of my invention to improve upon the method disclosed in that patent and to eliminate or materially reduce factors of error encountered in the employment of that method.

Another object of my invention is to provide a method of measuring the location of fluid level or other obstructions in well bores, in which the intensity of the pressure impulse introduced into the well may be varied to compensate for well depth and the character of the gaseous media through which the wave must travel to produce an echo of sufficient intensity to permit the same to be readily detected and translated.

Another object of my invention is to provide a method as set forth in the preceding paragraph wherein the pressure impulse may be so varied as to allow the detection and the separate determination of the location of a plurality of obstructions which may be encountered in the well.

Another object of my invention is to provide a method for the measurement of the location of fluid level or other obstructions in a well bore in which the pressure impulse introduced into the well produces an indication both of the fluid level

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and of the location of other obstructions in the well bore.

Another object of my invention is to provide a method of the character set forth in the preceding paragraph wherein the same pressure impulse introduced into the well to measure the fluid level or the location of other obstructions is employed to determine the velocity of the wave in the particular media encountered in the well.

Another object of my invention is to provide a method as set forth in the preceding paragraph wherein, knowing the location of one or more obstructions, tools or other devices in the well bore, the velocity of the wave within the well bore may be accurately determined from echoes produced thereby and enabling an operator to determine the unknown location of the fluid level by the mere measure of the elapsed time between the introduction of the impulse into the well and the reception of a distinguishable echo from the fluid level, without necessitating introduction of corrective factors or other separate measurement of and determination of the character of the media in the well.

Another object of my invention is to provide a method for determining the location of fluid levels in well bores in which the location of and the number of tubing sections in the well may be determined by the same pressure wave created to measure the depth or the location of the fluid level.

Other objects of my invention will be apparent from a study of the following specification, read in connection with the accompanying drawing, wherein

Fig. 1 is a diagrammatic view illustrating a typical well cross section and the location and character of the apparatus required for determining the fluid level or location of other obstructions in the well in accordance with my method;

Fig. 2 is a diagrammatic view illustrating the type of record or indication which may be made with my method in its simplest application;

Fig. 3 is a diagrammatic view similar to Fig. 2 and illustrating the type of record or indication which may be made with my method but in which echoes produced by intermediate obstructions are not amplified; and

Fig. 4 is a diagrammatic view similar to Figs. 2 and 3 and illustrating the type of record or indication which may be made with my method, including the amplification of echoes from intermediate obstructions.

The method disclosed in United States Letters Patent issued to Wyatt and Lehr, hereinbefore referred to, is briefly that of introducing into a well bore a pressure impulse, either positive or negative, which may have any desired frequency as by the introduction into the well of a quantity of gas of known pressure and volume, the introduction of this impulse into the well producing a wave which will travel down the well until it encounters the fluid surface in the well and then the wave will be reflected and will travel back up the well to the ground surface where the echo or return wave may be detected, the measurement of the elapsed time between the production of the impulse and the arrival at the ground surface of the echo constituting a measure of the location of the fluid level by the simple calculation of the elapsed time multiplied by the rate of travel or the velocity of the wave in the well. In making such calculations, it is correctly assumed that the wave will act like an acoustical wave and its velocity will be the same as that of a sound wave. In air at normal temperatures and approximately sea level pressure this rate would be 1100 feet per second but the gaseous content or media in the well is ordinarily not the same as air and correction must be made for the density, temperature or other characteristics of the particular media encountered in the well, it being well known that the higher the temperature or the lower the density of the gaseous media through which the impulse travels the greater the velocity of the wave.

In employing the method as set forth in the said patent, an approximation of the fluid level may be readily determined and this approximation or measurement may be determined in a relatively short length of time, without requiring the removal or disturbance of any of the apparatus contained within the well bore. However to determine the fluid level with considerable accuracy, the rate of travel of the wave in the particular media encountered in any particular well must be known or must be determined since the density, temperature and character of the gaseous media in wells varies in each different oil field and in each individual well. I provide means for readily determining the pressure wave velocity in any particular well, which may be arrived at as follows:

In Fig. 1, I have illustrated a typical oil well comprising the earth bore 1, usually lined with casing 2 or pipe of relatively large diameter, extending from the ground surface at 3 to the oil bearing sands at 4 where the casing is either perforated or is provided with a perforated liner through which the oil from the sands may enter to the interior of the casing. The casing is, of course, constructed of a plurality of lengths of pipe secured together by couplings or collars in any well known manner. A second pipe or string of pipes extend down through the casing 2, the string of pipe being known as the oil flow tubing indicated at 5, extending from the ground surface down to a position disposed below the level of the fluid in the well, which is indicated at 6, the lower end of the tubing string 5 having a pump 7 of any desired character located therein. Such pumps are usually operated by means of a string of sucker rods 8 which extend upwardly through the tubing string 5.

It is the common practice to employ in the tubing string 5 a tubing catcher 9 which may be of any of the well known constructions, the tubing catcher being usually located a relatively short distance above the level of the pump in the well so that should the tubing string break the tubing catcher 9 will grip the casing and prevent complete destruction of the tubing string. One or more of the tubing catchers 9 may be distributed throughout the length of the tubing string.

The tubing string 5 is constructed of a plurality of lengths of pipe coupled together by means of collars 10, which collars are usually of somewhat larger outside diameter than the outside diameter of the tubing from which the oil flow tubing is made.

Hence it will be noted that in the ordinary oil well there are a plurality of obstructions, each of which is capable of receiving and reflecting a sound wave or pressure wave passing down through the well, these obstructions including the fluid surface 6, the tubing catcher 9 and each of the collars 10 of the tubing string.

In most wells the length of the tubing string between the ground surface 3 and the pump

is known, that is, records are usually kept showing the length of each tubing string section and the number of such sections located within any given well. Particularly, records are usually kept as to the location along the tubing string of the catcher 9 so that by referring to these records an absolute calculation or determination of the distance between the ground surface and the tubing catcher or liner top is known. Hence to determine the location of the fluid level 6, it is only necessary to produce in the well a pressure impulse which will create the low frequency wave, and then translate the echoes received from the well in terms of echo impulses received from the tubing catcher or liner top and from the liquid surface. By comparing the time lapse between the production of the pressure impulse and the receipt of the echo from the tubing catcher with the time lapse between the creation of the pressure impulse and the receipt of the echo from the fluid surface, a positive and accurate measurement of the location of the fluid level may be obtained. That is, if the known location of the tubing catcher is 5000 feet below the ground surface and it is desired to know the height of the fluid in the well, all that is necessary is to produce a pressure impulse, note or record the echo from the tubing catcher, and note or record the echo received from the fluid surface.

The time lapse between the creation of the pressure impulse and the receipt of the echo from the tubing catcher denotes the velocity of the pressure wave in the particular media encountered in that particular well so that by measuring the additional elapsed time between the receipt of the echo from the tubing catcher and the receipt of the echo from the fluid surface, an accurate measurement may be obtained and no compensation need be made for possible errors due to different velocities of waves in different media because the mean velocity of the wave from the ground surface to the tubing catcher and return is the same as the mean velocity of the wave from the ground surface to the fluid surface and return.

The only item which must be provided for is that of producing a pressure wave echo of such magnitude and of such character that the echo from the tubing catcher can be distinguished from the echo received from the fluid surface.

As illustrated in Fig. 1, this distinction may be readily made by providing a suitable source of fluid pressure indicated at 11 which may be a tank, compressor or other source of fluid pressure at any desired value. It follows, of course, that the pressure impulse which must be produced in the well must be at a greater pressure than the pressure of gases in the well so that the pressure source 11 must be capable of delivering a pressure impulse having a considerable differential over the static pressure of gases in the well or flowing therefrom. For example, if the well gases at the surface of the well are at a pressure of 500 pounds per square inch, the source of fluid pressure 11 must be capable of delivering, say, 600 pounds per square inch or more in order to create a pressure impulse of, for example, 100 pounds pressure differential.

The pressure source 11 is illustrated as being coupled to a pressure chamber 12, one end of which is connected as by means of tube 13 and valve 14 to the pressure source 11, while the opposite end of the pressure chamber 12 is connected by means of a nipple 15, a quick opening valve 16 and a nipple 17 to a length of pipe 18 which is in turn coupled as indicated at 19 to the well casing 2. The pressure chamber 12 is preferably provided with a suitable indicating pressure gage 20 by which the pressure within the pressure chamber 12 may be readily measured. Thus for the production of the pressure wave all that is necessary is to close valve 16, open valve 14 and allow pressure to be built up in the pressure chamber 12 to the desired pressure value, say, 600 pounds per square inch. Then the valve 14 is closed and valve 16 opened, allowing an impulse of 600 pounds per square inch to be injected into the well casing (the static pressure in which is, for example, 500 pounds per square inch).

A receiving device for receiving and registering the echoes of the pressure impulse from the various obstructions within the well is illustrated as including the pipe 18 and pressure responsive device coupled thereto through a valve 21 to a diaphragm chamber 22, permitting a flexible diaphragm 23 to be placed into communication with the casing 2 whenever the valve 21 is opened. To control the sensitivity of response of the diaphragm 23 and in order to prevent undue distortion of the diaphragm 23 by the static pressure in the well and to avoid damage which would result therefrom, I prefer to allow the static pressure in the well casing 2 and pipe 18 to be equalised on both sides of the diaphragm 23 as by providing a by-pass 24 providing a restricted passage through which gas pressure in the chamber 22 on one side of the diaphragm may pass to the opposite side of the diaphragm, the filter 25 being interposed in the by-pass if desired to dry out the gas and prevent undue corrosion of the more delicate parts of the device contained in the diaphragm chamber 22. Attached to the diaphragm 23 is a mirror 26. In the front wall 34 of the diaphragm chamber 22 I mount a lens 35, through which light from a suitable light source 36 may pass into the chamber 22 to be reflected by the mirror 26, the reflected beam 37 passing back through the lens 35, as a ribbon beam which may be reflected or directed upon a ground glass screen 38 and upon a recording chart or strip of sensitized tape 39 to make a permanent record of the path described by the light beam 37. Suitable reflectors, such as indicated at 40, may be employed to direct the beam in any desired direction while a reflector 40a may be interposed in a portion of the ribbon beam 37 to direct a portion thereof upon the screen 38, suitable condenser lenses 40b and 40c being interposed in the beam to draw the same to a point beam upon the screen 38 and tape 39.

Thus as the pressure within the casing 2 is varied as by the pressure wave resulting from the pressure impulse created within the casing 2, the mirror 26 will be moved, the amplitude of its movement representing the amplitude of the pressure variation. As the echo of the pressure impulse from any obstruction within the well is received upon the diaphragm 23, the mirror 26 will be moved in accordance with the amplitude of the echo impulse and will cause the echo impulses to be registered for observation, both by directing the light beam 37 upon the ground glass 38 where the amplitude of the echo may be visually observed and by directing the light beam 37 upon the recording tape 39, a permanent record of the pressure wave which is created within the casing 2 may be made and this wave or chart will show peaks of varying amplitude, each of which peaks represents an echo from a particu-

lar obstruction within the well, either the tubing collars 10, the tubing catcher 9 or the fluid surface 6.

The sensitized strip 39 may be arranged to be driven at any desired speed by means of a variable speed motor 41 coupled to a suitable source of current 42 through a rheostat or other speed adjusting device 43 so that the tape or strip 39 may be driven at variable speeds.

By employing some device which will produce upon the record strip 39 a time lapse measurement, a direct comparison between the path described by the light beam and the lapse of time may be accomplished. I prefer to provide such mechanism including means for producing upon the strip 39 a series of dots or marks, each of which represents a fraction of a second, the line of dots or marks extending substantially parallel to the general direction of the wave chart described by the light beam 37. This may be readily accomplished by providing a disc 44 having a plurality of openings 45 therein adapted to be rotated in the path of a secondary light beam 46 emanating from the light source 36. The light beam 46 passing through the openings of the disc 44 may be projected upon the same sensitized strip 39 to describe a series of marks thereon, one for each of the openings 45.

One of the openings 45a is preferably larger than the remainder so that upon each revolution of the disc 44 a distinguishing mark will be produced. Thus by providing ten openings 45, a series of marks 48a may be produced upon the record strip 39 representing ten equal divisions. The tenth mark being produced by the large opening 45a is of greater length or of greater size or in some other manner distinct from the remaining nine marks. By providing the disc 44 with any suitable time mechanism such as a synchronous motor 47, the marks produced upon the charts will represent lapse of time; for example, each mark representing $\frac{1}{10}$ of a second while the space between the distinct marks will represent lapses of one second each.

Due to the fact that the depth of wells varies considerably and, further, due to the fact that conditions of obstruction or constriction of the space between the well casing 2 and the tubing string 5 varies considerably in different wells, the same pressure differential cannot be used successfully in all wells and it is necessary to vary the pressure impulse through considerably wide limits, dependent upon the conditions encountered at a particular well. For this reason I prefer to direct a portion of the beam 37 upon the ground glass screen 38 so that by firing one charge of gas pressure into the well and observing the path described by the light beam, a determination of whether or not the correct pressure impulse is being used may be made. For example, one pressure impulse which is estimated to be correct for a given well may not produce a sufficient fluctuation in the echo waves received from the tubing catcher and the fluid surface, and a higher pressure or greater quantity of gas must be used in order to create the desired impulse. Thus by observing the effect of a succession of pressure impulses liberated into the well, the person making the survey will be able to determine which of the echoes rebounds from the tubing catcher and which of the echoes rebounds from the fluid surface and thus determine when distinguishable echoes are being received from the different obstructions in the well.

The typical desired configuration of the path described by the light beam 37 is indicated in Fig. 2 wherein *a* represents the path described by the light beam as a result of the pressure wave created by a discharge of gas from the chamber 12 into the well casing. From an inspection of the line *a*, it will be noted that this line is a relatively straight but somewhat wavy line, having distinct peaks at *b*, *c* and *d*. The peak *b* is that which will be produced by the deflection of the diaphragm 23 when the impulse of gas from the chamber 12 is liberated into the casing 2. At a predetermined time thereafter, dependent upon the velocity of the wave in the particular well, a peak *c* will be produced as a reflection from the tubing catcher 9, while at a predetermined time thereafter an additional peak or series of peaks will be produced at *d* as a reflection of the wave from the fluid surface.

Thus by observing the effects of a series of pressure impulses of different intensity or pressure, the operator may determine which impulse is most desirable to produce the distinctly recognizable and differentiatable peaks *c* and *d*, allowing him to differentiate between echo from the tubing catcher (or such other obstructions as may be known to be in the well) and the echo from the fluid surface. As hereinbefore stated, knowing the depth or location of the tubing catcher 9, the comparison of the elapsed time between the peaks *b* and *c* and the elapsed time between the peaks *b* and *d*, an accurate determination of the fluid level may be produced.

After the most desirable magnitude of pressure impulse has been determined, the motor 41 may be set into action and a permanent record of the path described by the light beam may be made upon the sensitized film 39 with assurance that the various peaks *b*, *c* and *d* will be readily distinguishable upon the diagram so produced.

As will be observed from an inspection of Fig. 2, the diagram on the strip 39 also shows the plurality of spaced dots or other means of indicating elapsed time, such series of dots being indicated at 48a.

Having made a diagram as indicated in Fig. 2, a direct measure and determination of the fluid depth may be achieved. Also it will be observed that by selecting impulses of the desired magnitude, reflections from other obstructions in the well may be noted and recorded, thus assisting in the location and determination of other restrictions as well as a measurement of the fluid level.

For example, each of the collars 10 of the tubing string will produce a distinct echo differentiatable from the echoes from other sources. This allows the accurate measurement of the fluid level in a well where, by reason of failure to keep records or loss of records, the location of the tubing catcher is not known or wherein the catcher is submerged or is omitted. For example, in some wells tubing has been drawn out and replaced by other tubing and no record has been made of the lengths of tubing drawn out or the lengths of each section drawn out or the length or number of tubing sections employed to replace them so that to merely compare the time distance between the peaks *b* and *c* would not give a true indication of the velocity of the wave in the particular well. However, if it is reasonably assured that each of the tubing lengths is approximately the same, and the usual practice in oil wells is to employ tubing lengths in a given well, all of which are approximately the same, an indication of the number of tubing lengths located within any

given well, multiplied by the average length of a tubing section, will give a true measure of the location of the tubing catcher or the location of the pump or other device which constitutes an obstruction in the well. For example, by selecting a desired pressure impulse, by comparison of a succession of pressure impulses and the waves produced thereby, upon the ground glass 38, a wave or line of the character indicated at *a* in Fig. 3 may be produced wherein, though it is still wavy, it is produced by a series of peaks *e*. By counting the number of these peaks, each of which represents a reflection back from a collar 10, the number of lengths of tubing between the peaks *b*, *c* and *d* may be determined.

However, in actual practice it is found that irregularities in the annular space between the tubing and the casing, such as may be caused by imperfect abutment of adjacent casing sections or the presence of tubercules upon either the casing or the tubing will produce undesired echoes and will produce upon the record chart peaks which cannot readily be distinguished from those resulting from the echoes from the tubing collars, and I prefer therefore to provide some means which will be so tuned with the tubing collar echoes as to amplify or accent them and which will tend to dampen or filter out the undesired disturbance vibrations. As will be understood by those familiar with acoustics, if upon the multiplicity of sound waves emanating from the well as a result of the desired echoes and the disturbances there is superimposed another wave so tuned to the desired echo wave as to beat with it, the desired wave will be amplified and accented while the other or disturbance waves will tend to be damped out.

By selecting the correct length for the pipe 18, that is, by selecting the correct distance between the casing 2 and the diaphragm 23, a tuned wave may be produced which will affect the movements of the diaphragm 23. Since it is desired to count the number of tubing collars, all that is necessary is to lengthen or shorten the pipe 18 until it is tuned to one of the harmonics of the impulses or echoes produced by the collars 10. From experience it has been found that selection of the pipe 18 of approximately one-third of the length of a section or joint of the tubing 5 a third harmonic is produced which beats with the impulses echoed from the tube collars 10 to produce magnified or amplified peaks *e* and permits the ready distinguishing of the impulses produced by the collars 10 from other impulses.

I prefer, however, to employ in the length of the pipe 18 an adjustable coupling 19 which allows the accurate lengthening or shortening of the pipe 18 until, by observing the path of the light beam upon the ground glass 38, a distinct pattern is made represented by the line *a* on Fig. 4, in which each of the intermediate peaks *e* is amplified as indicated in Fig. 4 so that it is readily recognizable.

The adjustment of the coupling 19 should be made until, with a given pressure impulse, a uniform deflection of the mirror 36, that is, a uniform amplitude of the peaks *e*, is achieved, and by observing this upon the ground glass 38 the operator will note when the pipe 18 is of such length as to be "tuned" with the tubing lengths.

Thus, even though the location of the tubing catcher is not known, if the average length of tubing section is known, the production upon the strip 39 of a diagram such as shown in Fig. 4 allows the counting of each of the collars 10 and a clear understandable record is made of the length of tubing string between the impulses *b*, *c* and *d*, permitting the quick and accurate location and determination of the exact level of the fluid in the well.

As is described and claimed in my copending application Serial No. 270,866, filed April 29, 1939, an elongated tube or pipe 53 coupled as by means of a short pipe 54 to the pipe 18 and controlled by a valve 55 in such manner as to permit gas from the casing 2 to flow through the pipe or tube 53, thus providing in the pipe 53 an atmosphere corresponding to the atmosphere or gaseous medium in the casing 2. An open exhaust pipe 56 leads from the opposite end of pipe 53 open to the atmosphere or connected to a gas flow line so that the pressure within the pipe or tube 53 will remain substantially constant as of the value of the gas in the casing 2. Near one end of the tube 53, a diaphragm 57 may be provided and arranged to be vibrated at any desired frequency as by coupling the diaphragm 57 by a pipe 58 open to the atmosphere at 58*a*, to a source of fluid pressure, such as compressed air, indicated at 59. A rotary valve 60 is interposed in the pipe 58 and arranged to be driven by means of a variable speed motor 61 regulated as to speed by means of a suitable rheostat or other controlling device 62 so that by rotating the motor 61 at any speed a series of pressure impulses will be created in the pipe 58, and will beat upon diaphragm 57 to create a pressure wave in the tube or pipe 53 of known frequency, the frequency being variable by varying the speed of motor 61.

At the opposite end of the pipe 53 I couple a pressure responsive device which may be constructed in the same manner as the diaphragm chamber 22 and diaphragm 23 hereinbefore described. This pressure responsive device is illustrated at 63 coupled directly to the end of the pipe 53, the diaphragm 64 of which receives the impulses transmitted through the pipe 53 to vibrate in response thereto and to move a mirror 65 in the same manner as was described with reference to the mirror 26. The mirror 65 reflects a light beam from a suitable source 66 upon a polygon of mirrors 67 revolved by means of an adjustable speed motor 67*a* at a speed synchronous with the speed of the motor 61 so that the amplitude and uniformity of the vibrations of the diaphragm 64 may be visibly observed.

As is well known in the art, each gaseous medium, variable as to density, temperature, etc., is resonant to pressure waves or sound waves of predetermined frequency. Thus by varying the speed of operation of the motor 61 until the pressure impulse created by the diaphragm 57 makes one round trip (or multiple thereof) to the diaphragm 64 and back to the diaphragm 57 in time to just synchronize with the next impulse created by the diaphragm 57, the pattern described by the beam of light on the mirrors 67 will show maximum amplitude, and noting the frequency of the impulses produced upon the diaphragm 57 (that is, noting the speed of the motor 61) the velocity of the sound through this particular gaseous medium may be readily determined by comparing this frequency with the frequency at which a condition of perfect resonance is achieved in the pipe 53 with air in it.

It will therefore be observed that I have provided a method of determining the location of obstructions in wells and accurately locating and measuring the fluid level in a well without the

necessity of removing any of the apparatus from the well, the entire measurement and determination being accomplished in a relatively short time.

It will be understood by those skilled in the art that the creation of pressure impulses within the well may be accomplished by decreasing the pressure in the well instead of admitting a charge of gas from the pr sure chamber 12 into the well. For example, if the pressure in the well is relatively high, the valve 16 in the pressure chamber may be closed and the valve 14 opened, allowing the pressure in the chamber 12 to reduce to some value less than the casing head pressure of the well. Then by closing valve 14, and opening valve 16 a measured quantity of gas will rapidly discharge or surge into the chamber 12, creating a pressure impulse within the well which acts in the same manner as hereinbefore described for the introduction of pressure from the tank or other source 11.

It will also be understood that if desired special constrictions may be placed in the well for future measurements of the fluid level therein to take the place of the tubing catcher 9. Such constrictions could comprise a closed cylinder of pipe surrounding and attached to one of the tubing sections when the tubing is run into the well and by noting and recording the location of such constriction, the future measurements of the fluid level by my pressure impulse method can be readily determined, employing the reflection of the wave from the restricting member in place of the reflection from a tubing catcher 9 or other restriction in the well.

While I have shown and described the preferred embodiment of my invention, I do not desire to be limited to any of the details of construction shown and described herein, except as defined in the appended claims.

I claim:

1. The method of accurately determining the unknown location of an obstruction in a well having a string of tubing therein constructed of a plurality of lengths of tubing, each of approximately the same length and connected to each other by couplings, which consists in creating a pressure impulse in the annular space between the tubing and casing of the well, registering the echoes from the tubing collars and from said obstruction, and counting the tubing collar echoes occurring between the creation of the pressure impulse and the echo from the unknown obstruction, to determine the location of the unknown obstruction.

2. The method of determining the unknown location of an obstruction in a well having a string of tubing therein, which consists in creating an acoustical impulse in the annular space between the tubing and the well casing to produce echoes from portions of the tubing string distinguishable from each other and from the echo from the unknown obstruction, observing the lapse of time between the arrival at a predetermined point of the echoes from successive portions of the tubing string to thereby determine the velocity of the pressure wave through the particular well under measurement, and measuring the lapse of time between the creation of the pressure impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

3. The method of determining the unknown location of an obstruction in a well having a string of tubing therein, which consists in creating an acoustical impulse in the annular space between the tubing and the well casing of such magnitude as compared with the depth of the well and the resistance to pressure wave transmission therethrough as will produce echoes from portions of the tubing string distinguishable from each other and from the echo from the unknown obstruction, observing the lapse of time between the arrival at a predetermined point of the echoes from successive portions of the tubing string to thereby determine the velocity of the pressure wave through the particular well under measurement, and measuring the lapse of time between the creation of the pressure impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

4. The method of determining the unknown location of an obstruction in a well having a casing with tubing therein restricting the volume of the annular space within the casing and having another obstruction therein at a known location above the unknown obstruction, which consists in creating in the annular space an acoustical impulse to produce echoes from different obstructions distinguishable from each other, observing the time lapse between the creation of the impulse and the arrival at a predetermined point of the echo from the known obstruction, comparing with said time lapse the time lapse between the creation of the impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

5. The method of determining the unknown location of an obstruction in a well having a casing with tubing therein restricting the volume of the annular space within the casing and having another obstruction therein at a known location above the unknown obstruction, which consists in creating in the annular space an acoustical impulse of such magnitude as compared with the depth of the well and the resistance to pressure wave transmission therethrough as will produce echoes from different obstructions distinguishable from each other, observing the lapse of time between the creation of the impulse and the arrival at a predetermined point of the echo from the known obstruction to thereby determine the velocity of the pressure wave in that particular well, and measuring the lapse of time between the creation of the impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

6. The method of determining the unknown location of an obstruction in a well, which consists in placing another obstruction in the well at a known depth in the well, creating a pressure impulse in the well, observing the lapse of time between the creation of the pressure impulse and the arrival at a predetermined point of the echo thereof from the obstruction of known location, and measuring the lapse of time between the creation of the pressure impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

7. The method of determining the unknown location of an obstruction in a well having a casing with tubing therein restricting the volume of the annular space within the casing and having an approximately known depth and a known pressure of gas within said space, from which the approximate magnitude of acoustical impulse required to traverse the restricted space and produce echoes from the several obstructions in the well may be estimated, which consists in introducing into said space between the casing and

tubing a series of acoustical impulses, each of different magnitude approximating the estimated magnitude to produce from each impulse echoes from the different obstructions in the well, observing the echoes that are produced by each impulse to select the one that produces distinguishable echoes from each of the obstructions in the well, and recording the echoes of an impulse of the selected magnitude in the relative times and order in which they are received at the ground surface.

8. The method of determining the unknown location of an obstruction in a well having a string of pipe therein consisting of sections of known mean length connected by couplings, which consists in creating an impulse in the well adapted to produce an echo from each of a plurality of successive couplings and from the obstruction of unknown location, and sequentially registering the impulse and such echoes in spaced relation to each other proportional to the actual relative spacing of the couplings and the unknown obstruction, and computing the distance to the unknown obstruction from said known mean length between successive couplings and the number of registered coupling echoes.

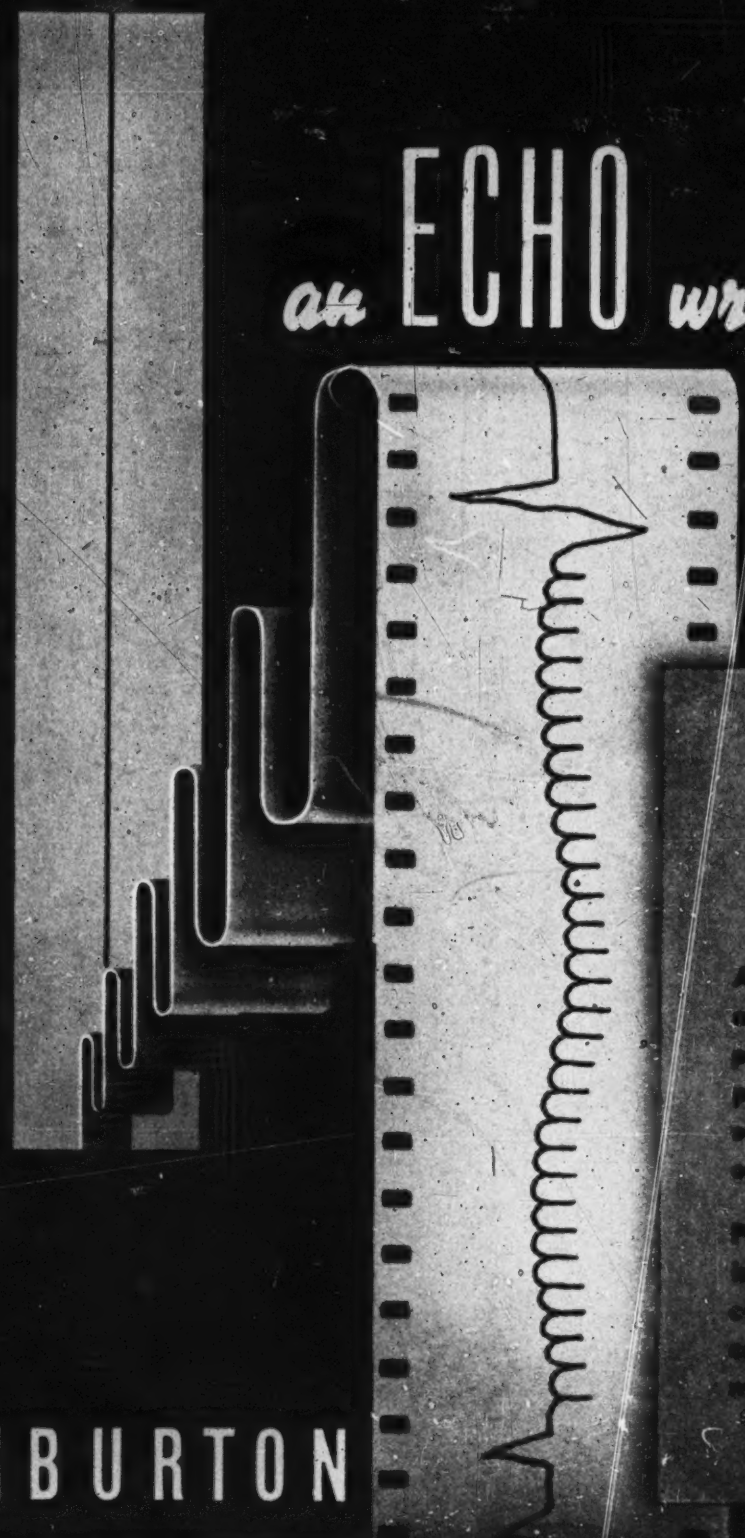
9. The method of determining the distance to an unknown location of an obstruction in a well having a casing with tubing therein restricting the volume of the annular space within the casing and having another obstruction therein at a known location, which consists in creating at some known point within the casing an impulse to produce echoes from said obstructions distinguishable from each other, sequentially registering the impulse and the echoes from said obstructions in spaced relation to each other, and determining the distance to the unknown obstruction from said known point of impulse by comparing the elapsed time between the registrations of the impulse and the echo from the known obstruction with the elapsed time between the registrations of the impulse and the echo from the unknown obstruction.

CRANFORD P. WALKER.

PLAINTIFF'S EXHIBIT No. ____

[Endorsed]: Filed Oct. 6, 1952.

an ECHO writes the fluid level of your well



ECHO-METER

A SERVICE

Accurate and economical fluid-level measurements are obtained in a pumping well without stopping the pump, pulling rods and tubing, or otherwise interfering with normal operations.

Pump efficiencies, gas leaking or improper pump submergence, well capacities and bottom-hole pressures can also be determined from these measurements.

HALLIBURTON

"ECHO-METER"

HALLIBURTON OIL WELL CEMENTING COMPANY

Halliburton ECHO-METER

For Accurate Fluid Level Determinations

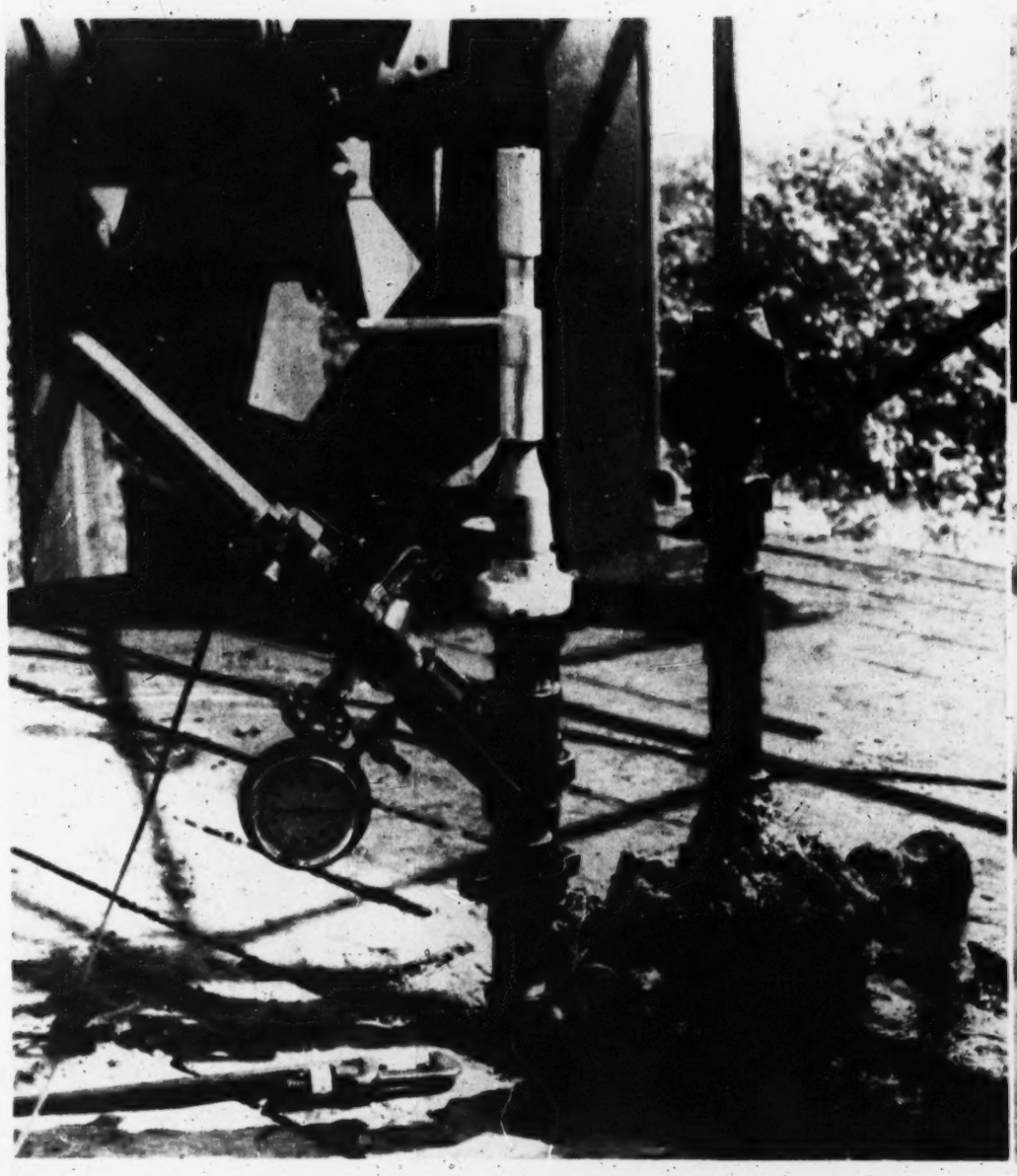
NOTE: The following pages are intended to acquaint the oil industry with the operation and application of a new HOWCO instrument, the ECHO-METER, which is not only an important aid in the production of oil but which is becoming helpful in the solution of many drilling, acidizing and cementing problems.—Daniel F. Elam, Echo-Meter Supervisor.

The ECHO-METER is an electrically operated instrument for recording the travel of a sound wave in an oil well, thereby locating the fluid level and certain other obstructions, and obtaining important bottom-hole information.

All measurements are made at the casing-head of the well, and it is not necessary to lower any kind of a mechanical device into the hole. No pulling of rods, tubing, or alterations of any kind to the well equipment are necessary, nor is expensive auxiliary equipment required. Production of oil or gas does not interfere with the normal use of the instrument, and the well can continue to pump, flow, or gas-lift while the measurements are being taken if it is so desired.

The ECHO-METER is an ideal instrument for measuring the fluid build-up, obtaining subsurface pressures, potentials, or productivity indices on producing wells. Data are quickly obtained for increasing pumping efficiencies. Other uses include measurements in drilling wells where mud circulation has been lost, or as a control instrument in certain acidizing and cementing procedures.

Versatility and speed of the equipment, plus accuracy and simplicity of the method, make the service extremely useful.



The Casinghead Unit can be con
taken from the car, and attached t

ECHO-METER EQUIPMENT

The ECHO-METER is simple. Complete equipment is carried in a 4-passenger coupe, with one jump seat removed to accommodate the instruments. Space for appurtenant apparatus is provided in the rear of the car. The equipment consists principally of an electrical Amplifier, a pen Recorder, and a Casinghead Unit. Only the Casinghead Unit is unloaded from the car at any time. This Unit connects to all standard well heads by a 2" nipple and quick-change union; it can be attached by an ell or other convenient fitting, and used in any position—horizontal, vertical, or otherwise. The Unit comprises a gun, for initiating a sound wave, and a microphone for detecting the echoes of this wave from the well.

The ECHO-METER is practical. The special type microphone used is extremely sensitive to the low frequencies which convey the desired informa tion; yet it is undersurbed by the high frequencie which are due to reverberations in the casing or t mechanical impacts. The results of a hamme blow on the outside of the microphone housing i hardly visible on the record, whereas a gentle wavin of the hand past the microphone gives a strong an unmistakable signal.

The ECHO-METER is rugged. The Amplifier i of special trouble-free design which will amplify lo frequencies without distortion. It incorporates microphone current control, multi-circuit curren meter, dynomotor power supply, and the necessar control relays and switches, in addition to an electr cal filter for eliminating disturbances caused b pumping or gas noises.

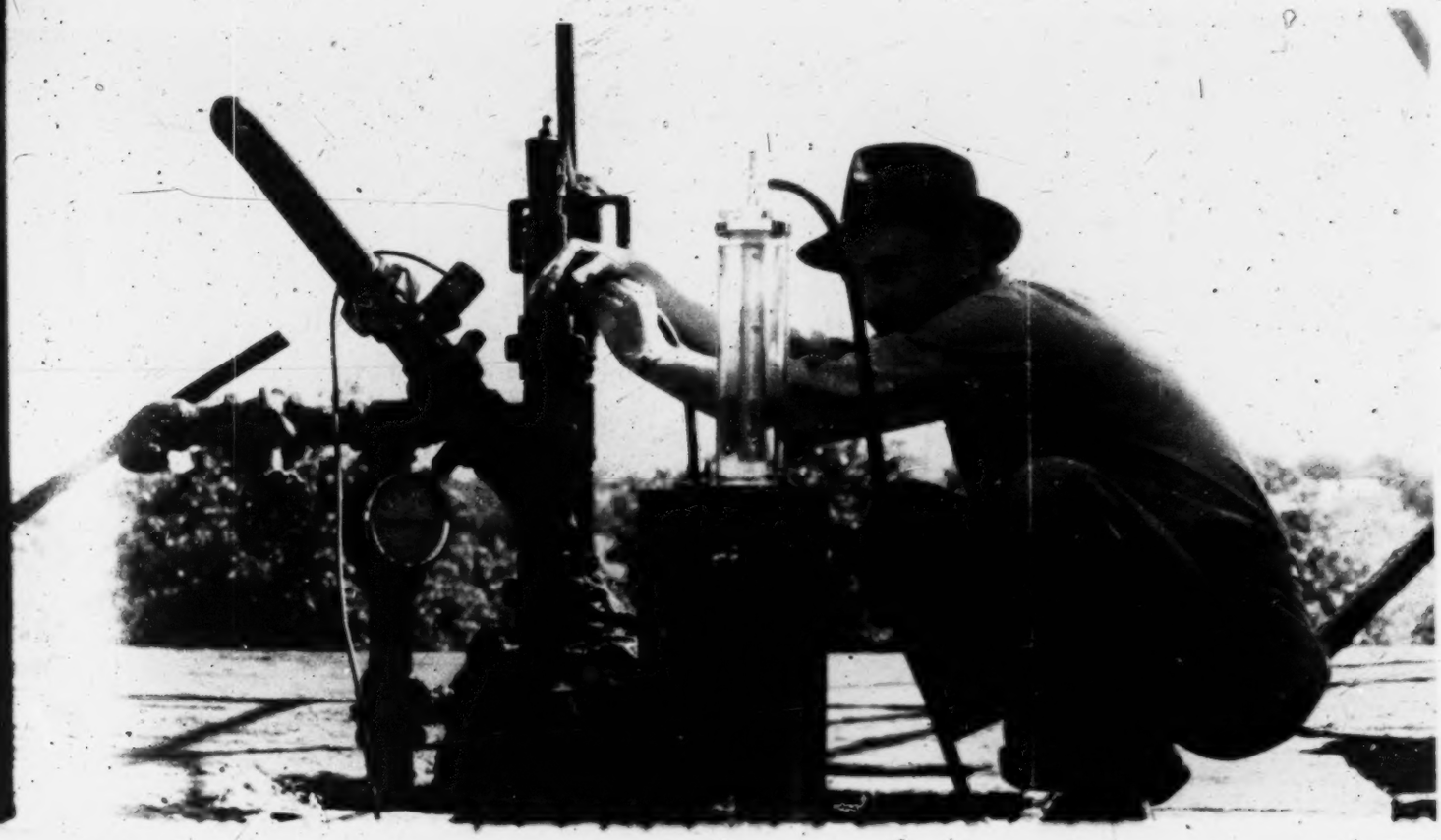
The ECHO-METER is convenient. Among the exclusive features is the electromagnetic Direct-Writing Recorder. It records an ink line directly on a continuous moving 35mm. paper tape, which passes under the recording pen at a known constant speed. The sprocket perforations in the tape serve as timing marks, while the ink trace is a record of well depth. The ink recorder completely eliminates the delay and inconvenience encountered by photographic methods. It also affords the operator visual control of his record at all times, enabling him to continuously and properly increase the electrical amplification of the weaker signals from the deeper parts of the well as they are being recorded.

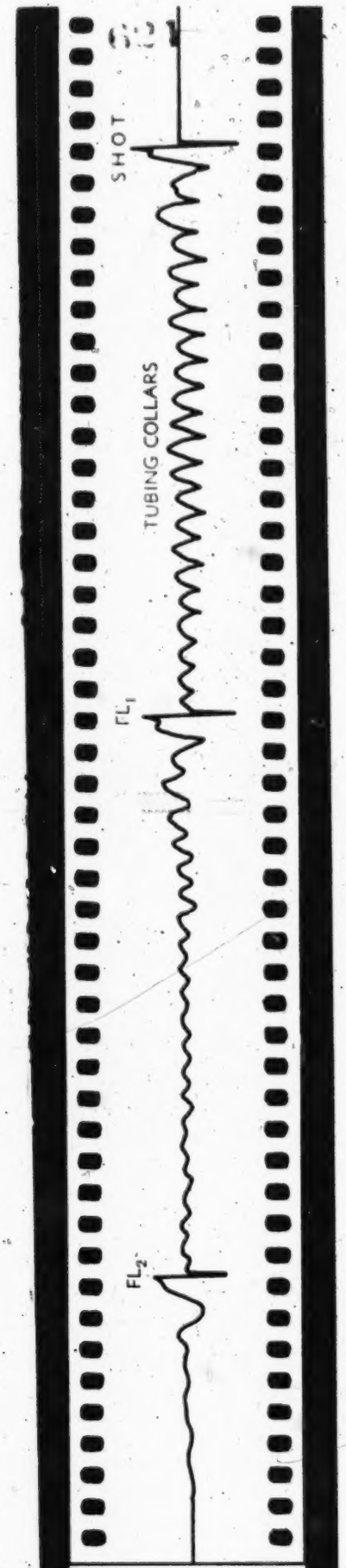
PRINCIPLE OF OPERATION

A steep-front sound wave is created in the Casing-head Unit by automatically firing a blank cartridge through a flame arrestor. When the cartridge is discharged, the sound wave goes down the annular space between the tubing and casing. All obstructions encountered by the wave give rise to reflections in proportion to the size of the obstruction; tubing collars give small reflections and tubing catchers and liner tops give larger reflections, while the fluid surface reflects almost all of the wave reaching it. No reflections are obtained below the fluid surface. The equipment is responsive to either compressional (positive) or rarefaction (negative) waves. Therefore, whenever desirable, tubing collars can be recorded inside the tubing instead of outside, provided the tubing is shut-in and is not full of fluid.

Pen and ink records are quickly computed.

Auxiliary tests can be completed while at the well.





Record 1

Shows multiple reflections caused by reciprocation of the initial sound wave. Normal dissipation of the wave energy can be noted by comparison of the two reflections.

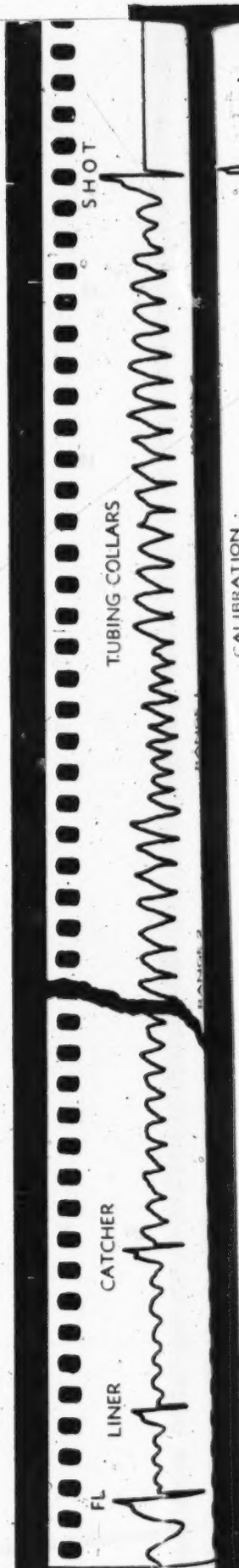
Energy from the shot, and likewise from the reflected sound wave, is picked up by the microphone and transformed into electrical energy. It is then carried by a plug-in cable from the mike in the Casinghead Unit to the instruments mounted in the car. Here the signals are amplified and filtered before being conducted to the Recorder, where they are instantly written in ink on paper. The record is therefore ready for interpretation within twenty seconds or less after the gun is fired. If successive records are desired, they may be taken at intervals of about thirty seconds, as the gun may be re-loaded for a second shot while the first one is still being recorded.

If the recording tape is permitted to run for a sufficient period of time, "multiple" fluid reflections, caused by successive travel of the sound wave between the well head and the fluid surface, will be recorded until the energy from the shot has been completely dissipated. (Illustrated by Record 1). These "multiple" reflections are sometimes helpful in the interpretation of records because of the similarities which appear at repeated intervals, or in cases where minute changes in the fluid level must be detected.

COMPUTATION OF RECORDS

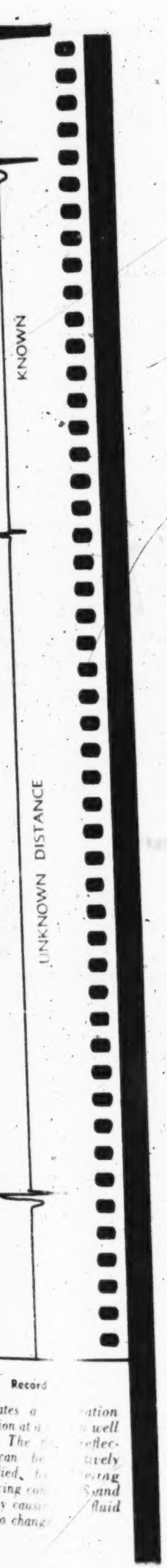
In the normal use of ECHO-METER equipment, the gun will be fired into the casing annulus. Therefore, each joint of casing and tubing exposed above fluid will tend to slightly obstruct the sound wave as it travels downward, and will cause small impingements to reflect back to the microphone at the casinghead. Since the magnitude of these reflected waves is dependent upon the percent change in cross-sectional areas of the annulus, it can be seen that reflections from casing joints are inferior in magnitude, or signal strength, to those caused by tubing couplings, and therefore will not be discernable. Thus, each of the stronger reflections caused by tubing collars is readily apparent on the ECHO-METER record, and the depth to fluid in the hole is obvious upon inspection of the tape.

Under average conditions, the depth to fluid can be interpolated to the nearest 0. 1 of a joint. Long subs at the top are usually indicated, and a tubing string of mixed joints wil normally show the relative joint lengths and sizes. (Illustrated by Record 2).



Record 2

Gives the fluid level below the tubing collars and the liner top. Note the 9 joints of short tubing in the top of string.



Record

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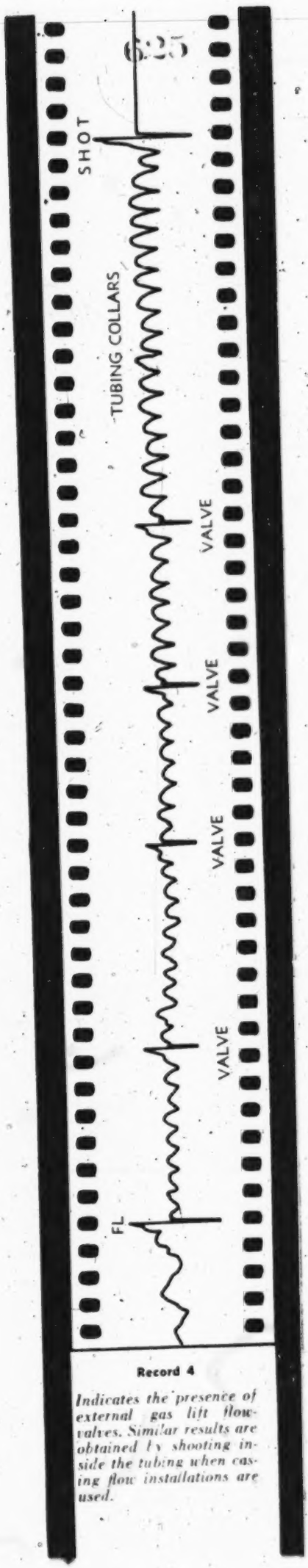
Whenever the fluid-level is below some known well depth marker, such as a flow-valve, tubing catcher, or liner top, no appreciable error is involved if depths are computed by proportional measurements of record lengths, as:

$$\frac{\text{Length of record to Catcher}}{\text{Length of record to Fluid}} = \frac{\text{Depth to Catcher in Feet}}{\text{Depth to Fluid in Feet}}$$

There are certain field conditions whereby a "calibration" measurement of well velocity may be advantageously used to give the fluid depth. A simple application of such procedure would be on a gas well not equipped with tubing or siphon. Then, a float or other large object to serve as a reflector can be lowered on a line some known distance, say 100', into the well. In the absence of tubing or casing collars, the ECHO-METER record will still show a "shot point," a "calibration" reflection from the float, and a "fluid" or its equivalent reflection from a deeper part of the well. By proportional record measurement, as explained above, the "fluid" can then be located directly in feet. Among other applications, this procedure can be used to follow acid down the hole when treating gas wells, and it will eliminate any danger of damage to a measuring line because of fluid heading. (Record 3).

In cases where tubing, or other well conditions would prevent the easy use of a wire line, a coil of hose or a copper tube of known length can be attached to the Casinghead Unit at the microphone. This hose is purged of air and allowed to fill with well gas. If the hose contains gas of the same composition and pressure as does the casing annulus, it will therefore, in effect, transmit sound at the same velocity. Strong signals arriving at the microphone are recorded in the conventional manner. These same signals are then recorded a second time after passing through the known "calibration" distance. The record is computed by direct comparison of its known and unknown lengths.

With careful work "calibration" apparatus is limited in accuracy to about ± 1% of the fluid depth. However, its use will give consistent results independent of tubing records, and the procedure affords an approximate check on tallys of doubtful accuracy.



Record 4

Indicates the presence of external gas lift flow-valves. Similar results are obtained by shooting inside the tubing when casing flow installations are used.

USES OF FIELD DATA

The most common and most simple type of ECHO-METER data is a single fluid-level determination. (Record 1). This can usually be completed in less than half an hour per well and will show much about the efficiency of pumping or gas-lifting equipment. Such defects as gas locking of the pump, improper pump submergence, or inadequate equipment are easily discernible, and by continuing the fluid-level studies, effective cures can be devised.

On a gas-lift installation, the fluid-level in the casing is readily determined, and the number of external flow-valves exposed above the fluid are shown on the ink record. Such ECHO-METER data are helpful in determining the proper valve spacings and in enabling the operator to watch his well's flowing performance from the service. (Record 4).

BUILD-UP STUDIES

A series of ECHO records, obtained at the proper time intervals, will plot in a smooth fluid build-up curve. When conducting such studies with the ECHO-METER, numerous wells may be worked at the same time, for the instrument is not tied-up on one well as is the bottom hole pressure recording gauge. Likewise, all data are available immediately for interpretation, and tests can be discontinued or extended on various wells according to their individual behaviours.

BOTTOM-HOLE PRESSURES

Bottom-hole pressures can be computed from ECHO-METER data, with a great saving of time and money in the instances where a pressure bomb cannot be easily put into the well. Static, or shut-in bottom-hole pressures can usually be determined from a single ECHO shot, but flowing or pumping pressure studies are conducted in a different manner and multiple fluid-level determinations are normally required.

The bottom-hole pressure is the sum of the casing-head pressure (P_h), the weight of the gas column (P_g), and the weight of the fluid column. The weight of

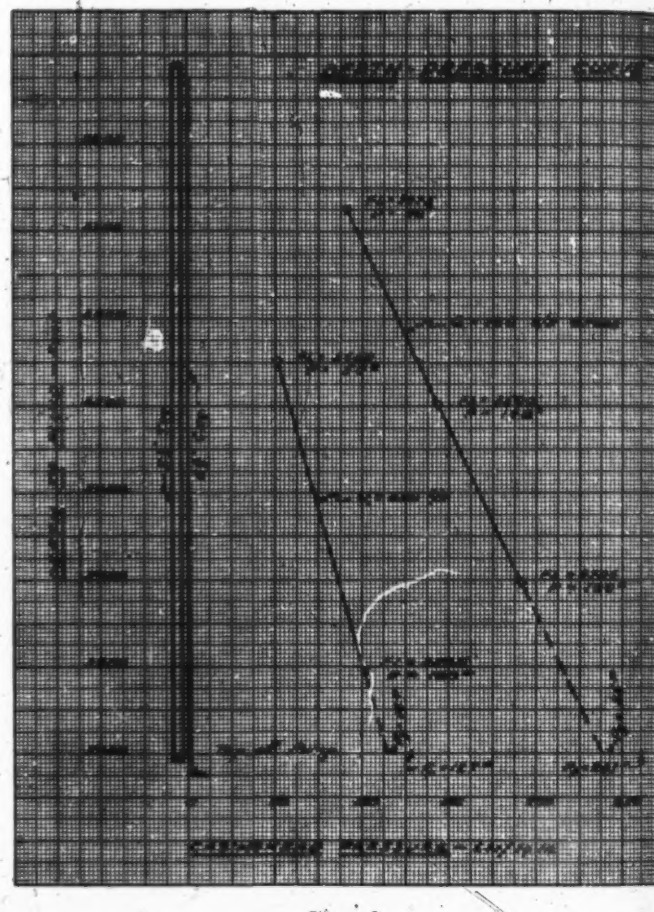


Figure 1

At any constant rate of production, a plot of equilibrium Fluid Levels vs. Casinghead Pressures will be a straight line. Extrapolation of this line to datum (in this case the pump) will show the casing pressure which, if reached, will maintain the fluid level in equilibrium at that point. Then the subsurface pressure at the pump (P_p) becomes equivalent to the total pressure of the gas above datum, or to the value of the extrapolated casinghead pressure plus the weight of the theoretical gas column (P_g).

the gas column can be determined if its length, specific gravity, average temperature, deviation from Boyle's Law, and surface pressure are known. (See charts inside back cover). The weight of the fluid is equal to its height (h) times the average density (d). Mathematically, the bottom-hole pressure may be expressed:

$$P_{bh} = P_h + P_g + hd \qquad (1)$$

The pressure bomb graphically records the total maximum pressure at any desired datum, but in ECHO-METER work the component parts of the total pressure are measured and the sum is computed mathematically, as all the factors involved are technically subject to individual measurement.

The pressure on the well casinghead can be gauged at the time of the shot initiation. The ECHO-METER record obtained is itself a measure of the length of the gas column. The specific gravity of the casing gas is easily and quickly determined with a portable measuring apparatus. (In ordinary field operations, the effects of temperature, deviation, etc., are of minor importance.) By subtracting the depth to fluid from the depth to the desired pressure datum, the height of the fluid column exerting pressure will be obtained. Substitution of the observed valves can then be made in equation (1).

In computing shut-in subsurface pressures, the average fluid density is generally known from previous experience and can be correctly assumed. If gradients are needed at different rates of production, measurements can be plotted for the changes in equilibrium fluid height at two or more different casinghead pressures and an extended line drawn through these points—thereby determining the casing pressure necessary to depress the fluid to any desired depth. (Illustrated by Figure 1.) When the fluid has been thus theoretically removed above the datum, the bottom hole pressure must be in equilibrium with the total pressure of the gas above. Therefore, the weight of the theoretical gas column at desired depth plus the extrapolated casinghead pressure at that depth will equal the datum pressure at the given production rate.

COMPUTATIONS FOR "WET" WELLS

Since the accuracy of ECHO-METER bottom-hole pressure calculations is dependent upon accurately determining the average density of fluid in the hole, it would appear that large quantities of water produced with the oil would cause the computations to be in error. At all producing rates where an appreciable draw-down of the fluid is obtained, however, the errors are minimized and nearly always are negligible for all practical considerations.

In a great majority of fields an appreciable separation of water from the oil usually takes place in the casing annulus, and a separation of the fluid into its components occurs when fluid equilibrium is reached at a given production rate. Since under this condition the pump is removing fluid at the same rate it is flowing into the well, the fluid below the pump is essentially of the same composition as that leaving the formation. In the annulus above the pump, where direct flow of fluid is not taking place, a quiescent condition will exist which permits gravitational seperation if the oil-water mixture is not too stable. The water and much of the bottom settlings will then be carried away by the moving fluid stream, leaving a measured column of fluid substantially of the same density as clean oil. The pump is then shut-down for the desired period, after which the amount of fluid build-up is determined.

When wells produce gas, the casing should be shut-in and the gas pressure allowed to build up to its highest practical value prior to shutting-down the pump, under which conditions the fluid height is determined. The gas pressure will cause the fluid-level to be as near the pump intake as possible, and thereby minimize any cumulative errors in computed density. Keeping the casing shut-in, the pump is then shut-down for the desired period, and the fluid-level again measured.

Fluid gradients are computed assuming that the fluid which was over the pump at the time it was shut-down was all clean oil. Likewise, the fluid which entered the hole during the time the pump was down is assumed to be of the same composition as that produced from the well while in an equilibrium condition.

Under certain conditions the pumping fluid-level may be omitted and the entire shut-in fluid column considered to be of the density of the oil-water mixture produced by the well. This will give an approximate bottom-hole pressure if the water percentage is not too high and if the fluid level can be depressed

almost to the pump before shutting in the well. For example, the density of clean oil produced will probably not run less than 30 lbs. sq. in. 100 ft. while the density of salt water will be approximately 45 lbs. sq. in. 100 ft. The maximum difference in the weight of a fluid column composed entirely of oil and one composed entirely of water is about 15 lbs. sq. in. 100 ft. Then in a hundred foot column of such fluid which contains one percent water the weight will be 0.15 lbs. greater than an equal column of clean oil.

It can readily be seen from these figures that, if the fluid column above the pump before the well is shut in is short, the resulting error in bottom hole pressure will not be large. For example, if there are 100 ft. of fluid above the pump before the well is shut-in and if the well is making ten percent water, the error in computed bottom-hole pressure will be only 1.5 lbs. sq. in.

WELL POTENTIALS AND THE PRODUCTIVITY INDEX

A calculated potential may properly be considered as a theoretical quantity, which represents the amount of oil a well would produce if the fluid could be taken from the well bore as fast as it entered. The ultimate capacity, or **theoretical** potential (Q), of a well would be obtained when the back pressure on the face of the producing formation was reduced to zero. Thus, the greatest pressure differential would exist between the reservoir (P_r) and the bore hole (P_{bh}), which would cause the fluid to enter at a maximum rate. Hence

$$Q = K(P_r - P_{bh}) \qquad (2)$$

Since Q is a function of the back pressure and is determined by that alone, it follows that if P_{bh} could be reduced to zero, Q would reach a maximum, which is the condition theoretically obtained in potential computations. Likewise, when the well is shut-in, $Q = 0$ and P_{bh} approaches equality with P_r. K is a constant of proportionality depending upon the dimensions of the system, and is proportional to the sand permeability. It is considered as a Productivity Index of the well, and is defined as "the barrels per day of gross liquid produced per pound per square inch pressure-drop at a specific subsurface datum."

Any condition tending to change the productive capacity of the well is indicated by a change in the

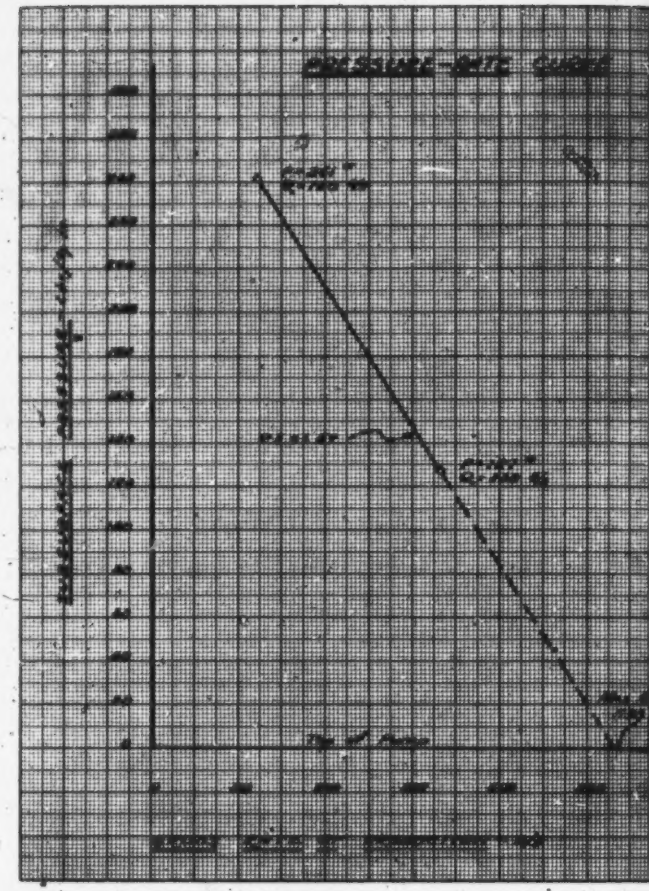


Figure 2

Datum pressures existing at various rates of production fall in straight line when plotted against their rates. The slope of th line determines the Productivity Index of the well; extrapolati shows the maxidm theoretical producing rate (Q), or potenti obtainable at the selected datum.

Productivity Index. A decreasing productivity w be obtained when the "gross production per pou drop in bottom-hole pressure" decreases. This co dition may be caused by increasing water, a decrea in effective permeability of the oil formation a jacent the well, or by drainage interference from of set wells. In some cases an increased productio factor may be obtained, especially if the well is clea ing out or channeling. Periodic measurements this index are a vital necessity in keeping a clos check on well performance. The decline of a well potential and changes in its producing condition can be intelligently followed, and in many case controlled, by the use of fluid-level data.

When wells have an ability to produce more flui than their equipment will handle, the old type physical pump or open-flow test is an unreliable in dex of capacity, as well as grossly expensive and e wasteful of reservoir energy. Such a test is merely demonstration of well equipment, and the outco m

o depends chiefly upon the size of tubing and or pump stroke employed. Some salient advantages of an ECHO-METER potential over a capacity physical test are:

1. Production rates which are harmful to the well are avoided. Reservoir equilibrium is disturbed a minimum, and less water is pumped during test.
2. A substantial back pressure is kept on the formation at all times during the test. This helps to prevent water coning and to alleviate "sanding-up".
3. Tests can generally be taken with regular well and field equipment. It is not necessary to install larger tubing, pumps, rods, and lead lines.
4. Less oil is produced during the test, requiring less tank storage.
5. Measurements can be made at convenience during regular work tours and do not need to upset labor schedules.
6. The actual cost of the test will be less. The service charge per well is nominal, and there are no "contengencies" and expensive break-downs of equipment to be feared. On pumping wells, no rods must be pulled in order to attach the instrument.
7. An accurate comparison between wells of their indicated producing abilities is obtained. "Loading" a hole with oil or permitting the shot hole to fill does not increase or alter the size of the potential as measured.
8. A Productivity Index of the well can be calculated from the ECHO-METER field data. Indices taken periodically will give a picture of the value of the well for tax and depletion estimates.
9. Comparative Indices can be used for approximating ultimate recoveries and economic limits. Such studies, when made in a new and undefined field, are invaluable to the land and exploration department.

Wh computing well potentials, measurements are tal at **low rates of production,** and the well's indicat performance at the higher rates is calculated from these data. A graph of experimental values with bottom hole pressure (P_{bh}) as ordinate and rate of production (Q) as abscissa will approach a straight line. Such a graph is called a "pressure-rate" curve (Figure 2), and when extrapolated to the Q intercept, i.e., the value of Q for $P_{bh} = 0$, yields the **theoretical** maximum rate of production since $P_{bh} = 0$ corresponds to a minimum back pressure on the formation face, (Equation 2). The negative slope of the pressure-rate curve is the Productivity Index.

The manner of conducting ECHO-METER potential tests varies, but it is dependent largely upon the gas-oil ratio of the well and upon the performance of the pumping equipment. In all cases the factors involved are bottom-hole pressure vs. different rates of production, and the method of measuring subsurface pressure determines the test procedure.

POTENTIAL MEASUREMENTS OF GAS-FREE WELLS

In wells operating at atmospheric pressure and which make little or no gas, the pressure on the fluid surface will be merely the weight of the gas column and has a negligible effect on the fluid-level. The height of the fluid within the well (which in this case is equivalent to the bottom-hole pressure) is then a function of the production rate only. Measurements therefore need be conducted only to determine the effects of the production rates upon the fluid height.

If the resulting values of equilibrium fluid height are plotted against their corresponding rates of production, a "draw-down" curve is obtained, (Figure 3), which extrapolated to zero fluid height yields the **theoretical** maximum rate of production, (Equation 2). The slope of the "draw-down" curve determines the Productivity Index of the well, which may be considered in this case as "gross production per foot of fluid draw-down".

Of converse relationship is the "Input Index" of a well, which is a measure of the formation's capacity for assimilating fluid. Such liquid capacity measurements are important in developing salt-water disposal projects, and observation of changes in the Input Index, indicating the probable formation of salt at the sand face, will aid in designing proper surface treatments for the water.

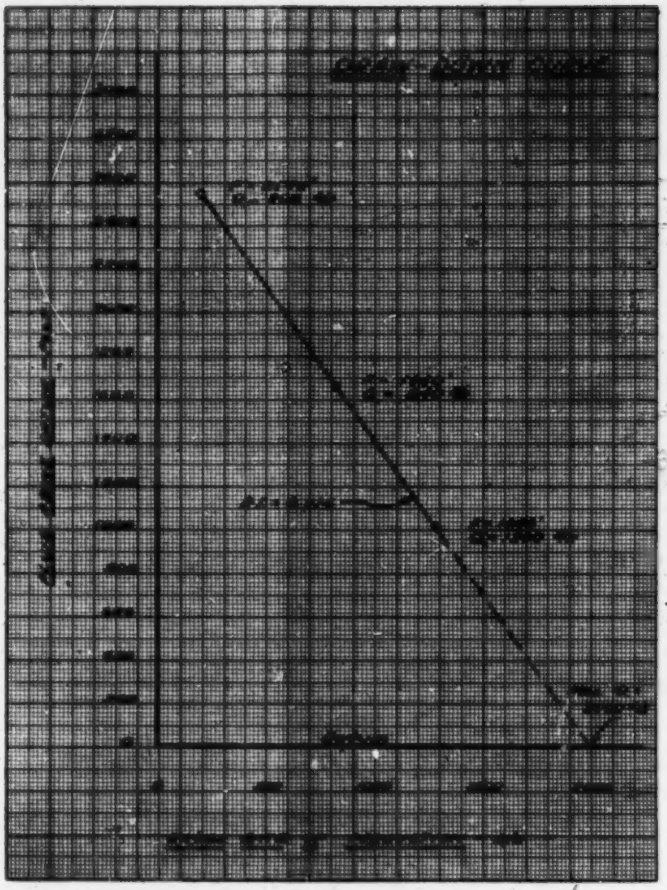


Figure 3

In gas-free wells, the height of fluid in the hole is proportioned to the rate of withdrawal. The negative slope of this "Draw-Down" curve is the Productivity Index, defined as "barrels per day per foot of fluid produced at equilibrium conditions." The maximum indicated potential (Q) is determined by extrapolation of the curve to datum, which is theoretically equivalent to withdrawing all the fluid from the well above this point.

POTENTIAL MEASUREMENTS ON HIGH GAS-OIL RATIO WELLS

When wells produce gas, the effects of the gas pressure on the fluid column must be determined, in addition to the effects of production rates. The effects of gas can be most easily observed by keeping the production rate constant, and measuring the changes in fluid-level at various casinghead pressures, as previously described. (See Figure 1). Thus, the bottom-hole pressure at a given production rate may be determined, and a "pressure-rate" curve drawn after two or more sets of such data are obtained (See Figure 2).

PRESSURE MAINTENANCE AND RE-PRESSURING

In large operations where it is desired to properly curb withdrawal rates from the individual wells and thereby to maintain the reservoir pressure at a uniform maximum, periodic detailed well studies are necessary. The same control is desirable when initiating and conducting reservoir re-pressuring programs. In both cases, ECHO-METER has been an invaluable guide successfully employed under widely diversified field conditions. Pumping and flowing wells may be taken alike, and due to the economy of the service, studies may be continued throughout the declining years of a field. This economy has enabled many projects to show a profit where otherwise the earnings would have been doubtful.

EVALUATION STUDIES

With the advent of proration, production men are seriously pressed for real values to sustain their holdings. ECHO-METER will assist them, for it embodies the simplest method and the fastest and most economical equipment yet developed for determining subsurface conditions in producing fields. It enables detailed studies to be conducted over large areas where heretofore only "key wells" could be measured and their averages drawn. ECHO-METER studies can be conducted in a short period of time, making the data truly relative, whereas old methods of measuring would take weeks or months in a large area and thereby rob the data of much significance.

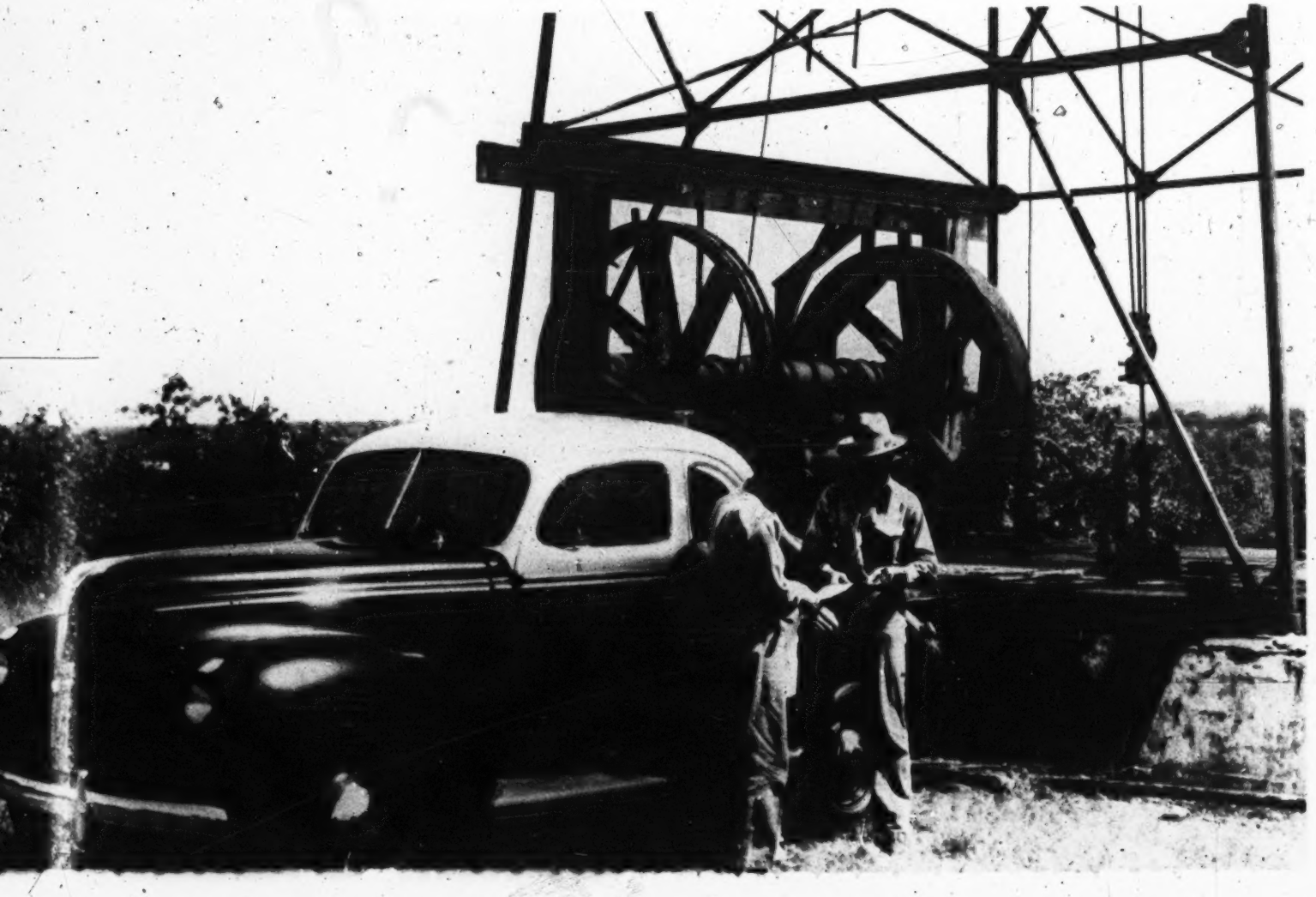
The Productivity Index, when plotted as a decline curve against accumulative production, becomes valuable in estimating ultimate recoveries and economic limits. Isobaric maps showing lines of equal bottom-hole pressure can be compiled, normally expressed with reference to a common datum plane. If two sets of contours are plotted, showing: (1) shut-in (static) bottom-hole pressure and (2) pumping equilibrium bottom-hole pressure at some given rate of production, these isobar maps will correspond to the Productivity Indices of the wells, and will give vital information on areas of higher permeability in the field. Such data make it possible for development work to be done in a better engineering manner, and this phase of the work grows in importance as the trend toward unit control of producing properties increases.

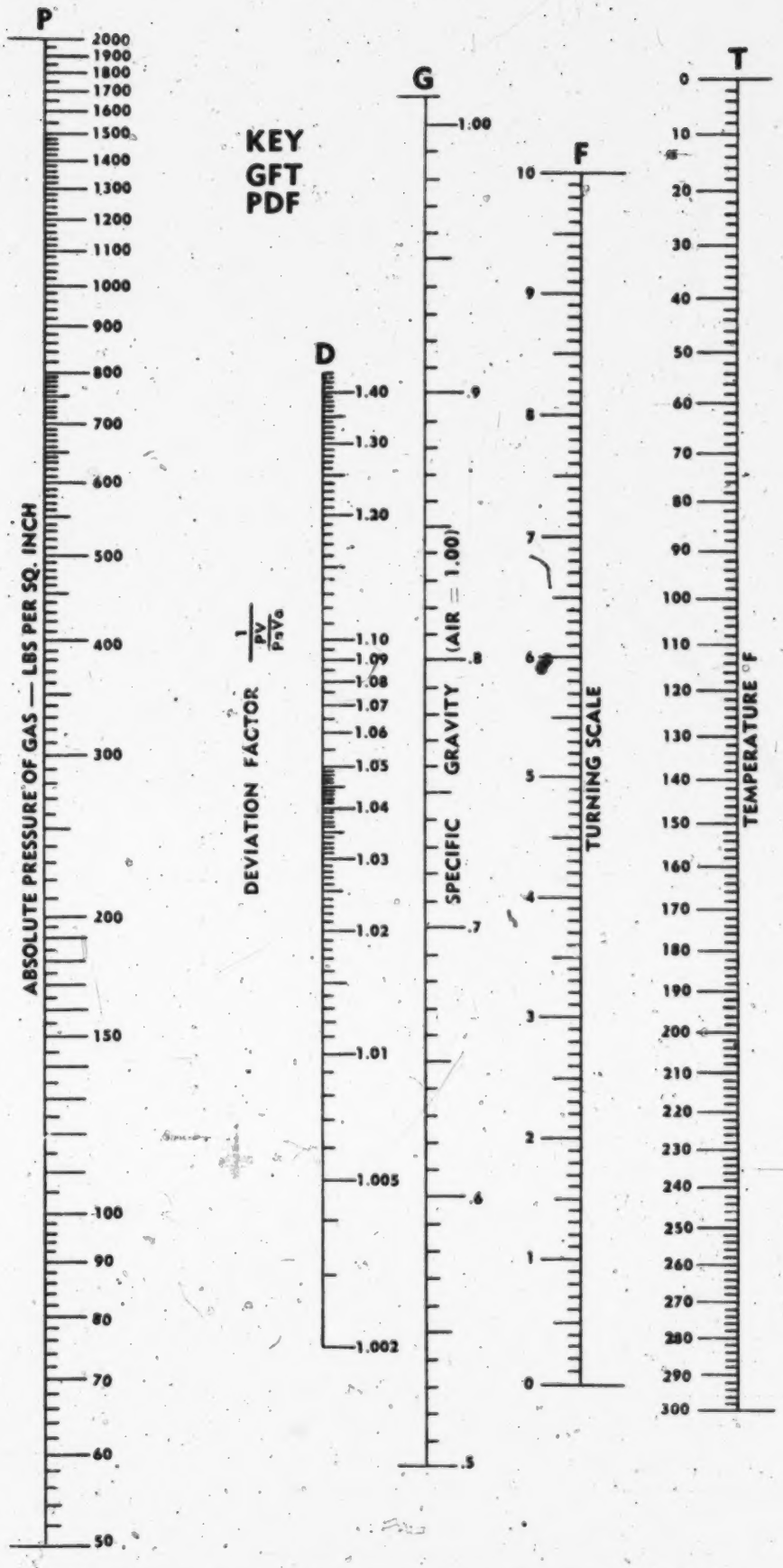
MISCELLANEOUS APPLICATIONS

Numerous occasions may arise in the conuct of drilling and exploration programs here the ECHO-METER will conveniently nd economically serve. By employing reections from either inside or outside the rill pipe, or some form of the "calibration" ethod of measuring, the fluid-level could e closely approximated in a hole which had lost circulation" of the drilling mud. In ases where flush joint drill pipe is used, emporary "reflectors" may be securely atached on the pipe at known intervals, and he fluid depth thus determined. In this vay, the ECHO-METER will aid materially n planning and in performing the necessary ement job.

In well cementing or acidizing operations, when fluid returns cannot be obtained at the casinghead, or where packers are employed, it is possible to directly and immediately measure minute changes of fluid-level in the casing annulus while the servicing operation is being performed. Thus, volumes and pressures can be computed just the same as if surface returns were had. Such measurements of the fluid-level can be made at desirable intervals by a sonic instrument under conditions which would be impractical for other types of measuring devices, and the value of an instantaneous pen-and-ink record of the fluid-level behaviour is readily apparent.

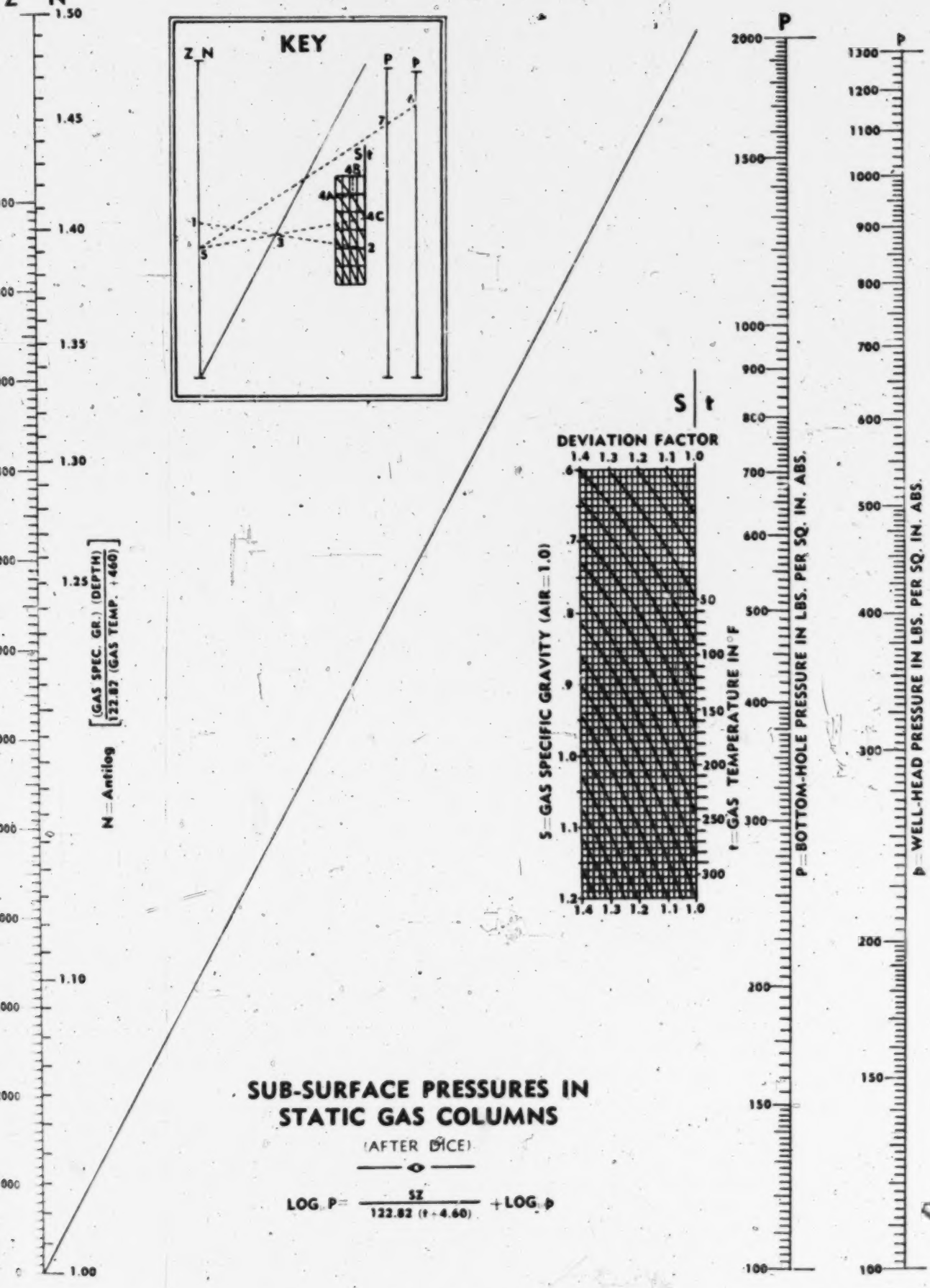
Discussing Echo-Meter Results with the operator





BOYLE'S LAW DEVIATION FACTORS FOR CO₂ AND AIR FREE PETROLEUM GASES

Volume at 14.73 #/□" Absolute and 60° F =
Observed Volume × Deviation Factor



SUB-SURFACE PRESSURES IN STATIC GAS COLUMNS

(AFTER DICE)

$$\text{LOG } P = \frac{SZ}{122.82\ (t + 460)} + \text{LOG } p$$

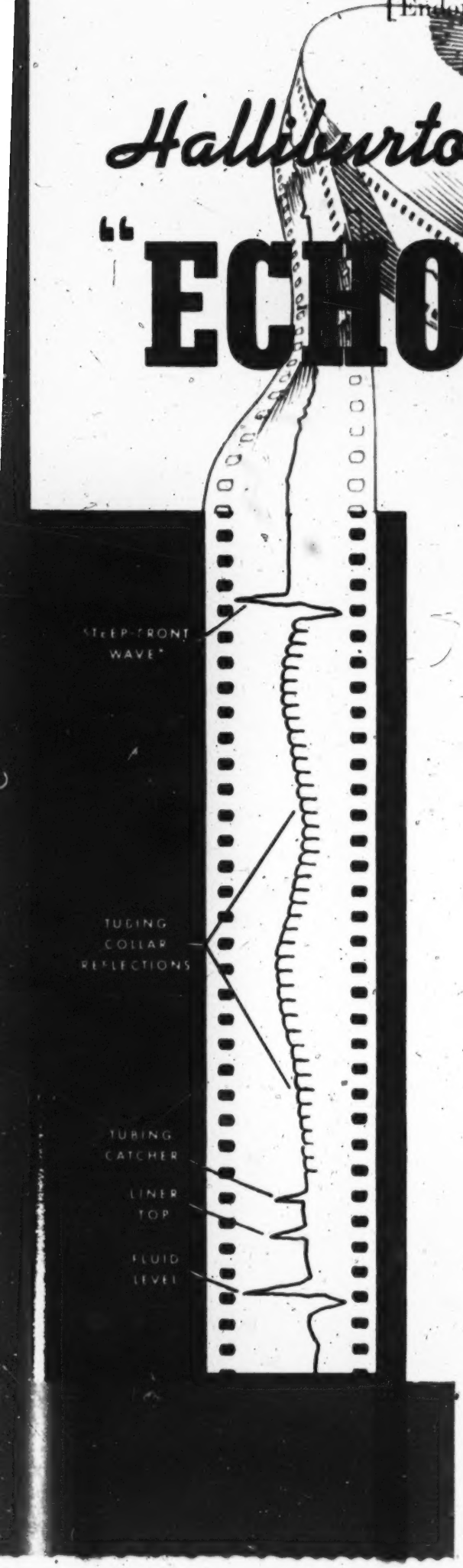
[Endorsed]: Filed Oct. 6, 1942.

Halliburton

"ECHO-METER"

(TRADE MARK)

for accurate fluid level determinations

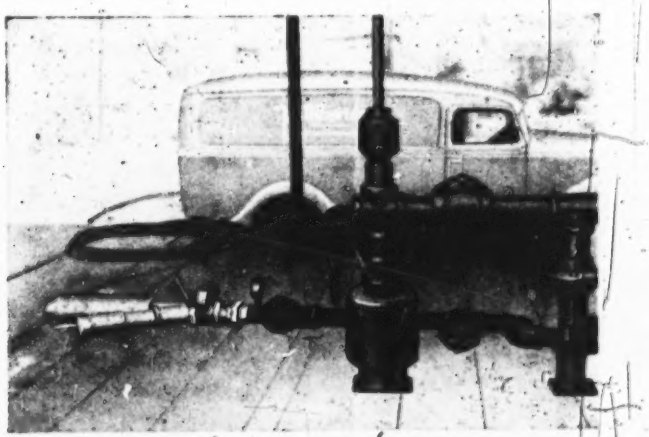


From ECHO-METER measurements of fluid levels in a well, it is possible to more accurately plan cementing plug-back jobs; to compile bottom hole pressure information for determining the potential and productivity of a well; to determine proper pump submergence, gas locking of the pump or adequacies of pumping equipment.

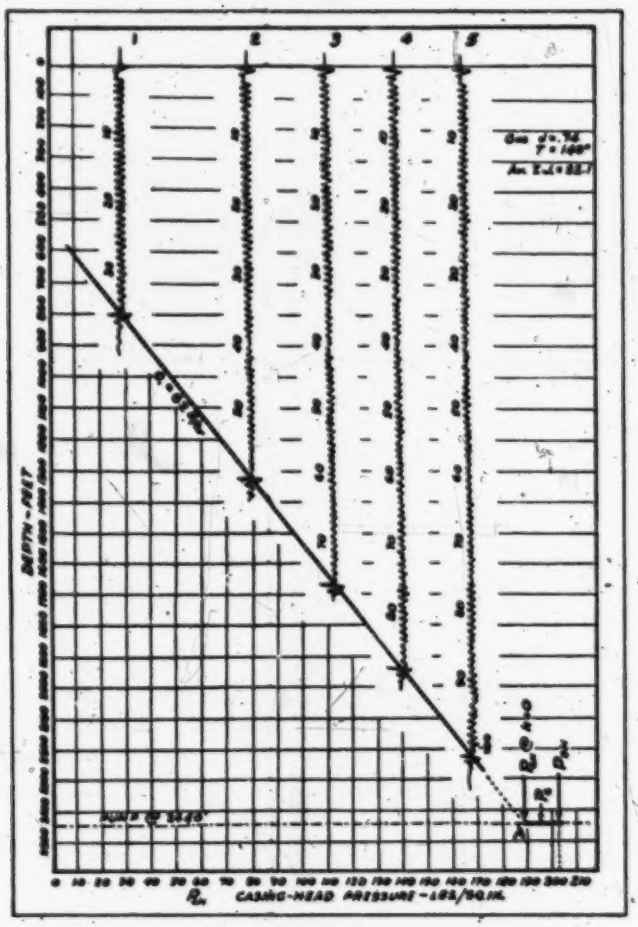
Location of the Fluid Level is obtained by recording the time required for a Steep Front Wave* to travel from the casing head to the fluid, and return. In addition to the reflections from the fluid level, other reflections are obtained from tubing collars, tubing catchers, and liner tops, providing a complete record of the internal conditions in the well.

The ECHO-METER Recorder* is of the newest direct-writing type. It gives an immediate ink record and eliminates the delays of photographic recording and developing. Utmost rapidity in making fluid level shots results in measurements of highest accuracy, as the small changes in fluid level may be followed.

*Method and apparatus patents are pending, covering all important phases of the ECHO-METER system and apparatus.



ECHO-METER Connected to Casing-Head



Example of Bottom Hole Pressure Determination by ECHO-METER Fluid Level Measurements

Bottom hole pressure measurements for any given rate of production are rapidly made by measuring the changes in equilibrium fluid height at two or more different casing head pressures—thereby determining the pressure necessary to depress the fluid to the desired depth. The illustration at top of the page shows the ECHO-METER records obtained for five different casing head pressures, and the computed bottom hole pressure at that given rate of production. The weight of the gas column, at the desired depth, is added to the casing head pressure, to give the total pressure necessary to force the fluid to that depth. When the height of fluid is theoretically zero, then the bottom hole pressure must be in equilibrium with the total pressure of the gas.

The bottom hole pressure is the sum of the casing head pressure (P_{ch}), the weight of the gas column (P_g) and the weight of the fluid column. The weight of the fluid is equal to its height (h) times the density (d). Mathematically the bottom hole pressure may be expressed:

$$(1) \quad P_{bh} = P_{ch} + P_g + hd$$

The ultimate potential or maximum production of the well is obtained by plotting a pressure vs. rate curve, i.e., plotting the bottom hole pressure versus different rates of production and then extrapolating the curve to zero bottom hole pressure. As shown by Equation (1) the maximum production will be obtained when P_{bh} is zero, since then the entire reservoir pressure is being utilized to drive the oil into the well. The productivity index is obtained by measuring the slope of the pressure-rate curve.

IMPORTANT OPERATION NOTES

1. All ECHO-METER measurements will be conducted by our trained operators. Due care and caution will be exercised, but we do not assume any liability for damages.
2. A readily accessible 2" pipe connection into the casing head shall be provided by the client. If the well is under pressure, a 2" gate or plug valve shall be installed at the casing head.
3. All manipulations at the well, such as opening or closing valves on gas or oil lines, changing pipe connections, changing pumping speeds, etc., shall be done by employees of client. The wells and their connected field equipment shall at all times be under the complete jurisdiction and control of the client. The client will furnish a man to be at the well during Fluid Level Measurements.
4. Gauging and reporting production, determining specific gravity of the gas, water content of production, and other control tests will be done by the ECHO-METER engineer upon request of the client. Charges for this work will be the same as those prevailing throughout the well measurements.

PLAINTIFFS' EXHIBIT No. 8-A

ECHOMETER FIELD DATA

Halliburton Oil Well Cementing Company
Duncan, Oklahoma

Company—Surf Associates Well—State # 1
Field—Huntington Beach

WELL DATA

Total Depth—4992 Plug Depth .....
Water String 8⅝ 36# Cemented—4463
Liner Size—5¾ 26# Length—564
Top of Liner—4428 Landed—4992
Perforations: From—4479 To—4992
Perforations: From .....To .....
Perfs: Size and Type—80 M - 16 R - 6" C Shop
Tubing: Size 2½ US Length—4856
Tubing Size .....Length .....
Total Tubing Length—4846
Number Joints—157
Average Joint Length—30.85

.....
.....

First Catcher Depth—3335 Type .....
Second Catcher Depth..... Type .....
Pump Depth—4846 Pump Size—2½x1¾x12
Pump Type—Axelson TL Gas Anchor: .....

.....

Gross Prod. B/D—70 Total Cut—12.5%
Net Oil B/D—62 Gravity API. Dry—25.5
Gas Fluid Ratio ..... Gas Gravity—.85
GasMCF/D .....
Static Fluid Level.....Date.....
Static Pressure.....Depth.....Date.....
Temperature..... Depth.....

TEST DATA

Date of Test—11/22/40

Time of Test	9:10	9:20	9:30	9:45	9:50	9:55
Pump Strokes/Min	15					
Length Stroke	28					

Casing Pressure	1#	1#	1#	1#	1#	1#
Fluid Level	4525	4525	4525	4525	4525	4525

By J. H. SHAW

Company..... Well..... Field.....

[Endorsed]: Filed Oct. 6, 1942.

PLAINTIFFS' EXHIBIT No. 8-B

ECHOMETER FIELD DATA

Halliburton Oil Well Cementing Company
Duncan, Oklahoma

Company—Surf Associates Well—State #1
Field—Huntington Beach

WELL DATA

Total Depth—4992 Plug Depth .....
Water String—8⅝ 36# Cemented—4463
Line Size—5¾ 26# Length—564
Top of Liner—4428 Landed—4992
Perforations: From—4479 To—4992
Perforations: From ..... To .....
Perfs: Size and Type—80 M - 16 R - 6" C Shop
Tubing: Size—2½ US Length—4856
Tubing: Size ..... Length .....
Total Tubing Length—4846
Number Joints—157
Average Joint Length—30.85

First Catcher Depth—3335 Type .....
Second Catcher Depth ..... Type .....
Pump Depth—4846 Pump Size—2½x1¾x12
Pump Type—Axelson TL Gas Anchor: .....

Gross Prod. B/D—71 Total Cut—12.5%
Net Oil B/D—62 Gracity API. Dry—25.5
Gas Fluid Ratio .....Gas Gravity—.85
GasMCF/D .....
Static Fluid Level.....Date.....
Static Pressure..... Depth..... Date.....
Temperature..... Depth.....

TEST DATA

Date of Test—11/25/40					
Time of Test	9:15	9:30	9:45	10:00	10:10
Pump Strokes/Min	15				
Length Stroke	28				
Casing Pressure	60#	60#	60#	60#	60#
Fluid Level	4745	4745	4745	4745	4745

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By J. H. SHAW

Company..... Well..... Field.....

[Endorsed]: Filed Oct. 6, 1942.

PLAINTIFFS' EXHIBIT No. 8-C

ECHOMETER FIELD DATA

Halliburton Oil Well Cementing Company
Duncan, Oklahoma

Company—Surf Associates Well—State #1
Field—Huntington Beach

WELL DATA

Total Depth—4992 Plug Depth .....
Water String—8⅝" 36# Cemented—4463
Liner Size—5¾ 26# Length—564
Top of Liner—4428 Landed—4992
Perforations: From—4479 To—4992
Perforations: From .....To .....
Perfs: Size and Type—80 M - 16 R - 6" C Shop

Tubing: Size—2½ US Length—4856
Tubing: Size ..... Length .....
Total Tubing Length—4846
Number Joints—157
Average Joint Length—30.85

.....

.....

First Catcher Depth—3335' Type .....
Second Catcher Depth ..... Type .....
Pump Depth—4846 Pump Size—2½x1¾x12
Pump Type—Axelson TL Gas Anchor: .....

.....

Gross Prod. B/D—162 Total Cut—12.5%
Net Oil B/D—142 Gravity API. Dry—25.5
Gas Fluid Ratio ..... Gas Gravity—0.856
GasMCF/D .....
Static Fluid Level ..... Date.....
Static Pressure..... Depth..... Date.....
Temperature..... Depth.....

TEST DATA

Date of Test—11/19/40

Time of Test	9:30	9:45	9:55	10:05	10:20	10:30
Pump Strokes/Min	17.2					
Length Stroke	42					
Casing Pressure	12	12	12	12	12	12
Fluid Level	4846	4846	4846	4846	4846	4846

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By J. H. SHAW

Company..... Well..... Field.....

[Endorsed]: Filed Oct. 6, 1942.

PLAINTIFFS' EXHIBIT No. 8-D

ECHOMETER FIELD DATA

Halliburton Oil Well Cementing Company
Duncan, Oklahoma

Company—Surf Associates Well—State #1
Field—Huntington Beach

WELL DATA

Total Depth—4992 Plug Depth .....
Water String—8⅝ 36 Cemented—4463
Liner Size—5¾ 26 Length—564
Top of Liner—4428 Landed—4992
Perforations: From—4479 To—4992
Perforations: From ..... To .....
Perfs: Size and Type—80 M - 16 R - 6" C Shop
Tubing: Size—2½ US Length—4856
Tubing: Size ..... Length .....
Total Tubing Length—4846
Number Joints—157
Average Joint Length—30.85

.....

.....

First Catcher Depth—3335 Type .....
Second Catcher Depth..... Type .....
Pump Depth—4846 Pump Size—2½x1¾x12
Pump Type—Anxelson TL Gas Anchor: .....

.....

Gross Prod. B/D—162 Total Cut—12.5%
Net Oil B/D—142 Gravity API. Dry—25.5
Gas Fluid Ratio ..... Gas Gravity .....
GasMCF/D .....
Static Fluid Level..... Date.....
Static Pressure..... Depth..... Date.....
Temperature..... Depth.....

TEST DATA

Date of Test—11/20/40
Time of Test 11:30 11:35 11:40 12:30 12:35 12:40
Pump Strokes/Min 17.2
Length Stroke 42

Casing Pressure	0	0	0	0	0	0
Fluid Level	4785	4785	4785	4785	4785	4875

By J. H. SHAW

Company..... Well..... Field.....

[Endorsed]: Filed Oct. 6, 1942.

PLAINTIFFS' EXHIBIT No. 9

Central Committee of
Calif. Oil Producers
Office of Oil Umpire
1160 Subway Terminal Bldg.
Los Angeles, California

SUBSURFACE PRESSURE TEST DATA

Potential Determination For Pumping Wells

(Information Confidential)

1134
Pumping F 14
6 5 40

Company—Surf Associates
Lease & Well No.—State #1

Field—Huntington Beach
Pool.....

AVERAGE PRODUCTION FOR PRETEST PERIOD

First 10 Days.....	111 B/D Gross	97 B/D Net	12.5% Total Cut
Last 3 Days	159 B/D Gross	139 B/D Net	12.5% Total Cut

CASING RECORD (Any Additional Casing Details Show on Separate Sheet)

Total Depth	4992 Ft.	Plug Depth	Ft.:	
Water String	8⅝"	36#	Cemented at	4463 Ft.:
Oil String	"	#	Landed at	Ft.:
564 Ft. of 5¾" 26# Liner			Top at	4428 Ft.:

TUBING RECORD

Size	2½"
	"
Pump Shoe at	4846 Ft.
Packer at	Ft.
Depth.....	4846 Ft.
.....	Ft.

Effective Perforations	Zone	Size & Type of Perforations
From.....4479 Ft. to.....4992 Ft.	.....	80 M - 16 R - 6" Shop
..... Ft. to..... Ft.	.....	.....
..... Ft. to..... Ft.	.....	.....

vs. Cranford P. Walker, et al. 643

Plaintiffs' Exhibit No. 9—(Continued)

PRODUCTION EQUIPMENT

Type of Pump—Axelson TL Pump Size—2½" Plunger Dia.—1¾"

Test	"A"	"B"	"C"	"D"	"E"	"F"
Date of Test	11/19	11/20	11/22	11/25		
Length of Stabilization Period, Hrs.	72	24	48	72		
Production Rate, B/D Gross	162	162	70	71		
Total Cut, %	12.5	12.5	12.5	12.5		
Net Oil Rate, B/D	142	142	62	62		
Gas Rate, MCF/D	32	25	28			
Pump Strokes per Minute	17.2	17.2	15	15	(No Static)	
Length of Stroke, Inches	42	42	28	28		
Casing Pressure, P. S. I.	12#	0	1	60		
Gas Column Weight P. S. I.	4	2	2	11		
Sonic: Total Pressure on Fluid Surface P. S. I.	16	2	3	71		
Sonic: Fluid Level, Ft.	4846	4785	4525	4745		
Sonic: Fluid Gradient in " Casing, PSI/Ft.						
Fluid Gradient 15¾ Casing, PSI/Ft.	0.309			0.309		
Recorder: Recorder Depth, Ft.						
Recorder: Pressure at Recorder, P.S.I.						
Recorder: Initial Tension of Recorder, P.S.I.						
Recorder: Temperature, °F						
Mean Formation Pressure, P. S. I.	24			90		

Plaintiffs' Exhibit No. 9—(Continued)

Oil Gravity (Dry) 25.5° API Gas Fluid Ratio.....Cu.Ft./Bbl. Gas Gravity .85

COMPUTED RESULTS

Minimum Mean Formation Pressure with Fluid Level at (Pump Shoe .....8 P.S.I.

Calculation: .....

$$\frac{162-70}{90-24}$$

Gross Productivity Index: .....1.4 Calculation: .....

Calculated Potential: .....184 B/D Gross.....161 B/D Net.....$(1.4\ (24-8)-\frac{162}{162})\ .875$

Potential Factor: .....182 B/D Gross.....159 B/D Net.....$(162\ (2-184))\ .875$

(For Recorder Method, Present Pressure and Production vs. Time Chart)

Remarks .....

.....

.....

Company Taking Measurements—HDWCO By—J. H. Shaw

Data Witnessed by..... Certified by..... Date.....

Potential Factor—159 Assigned for Month of Dec 1940

[Endorsed]: Filed Oct. 6, 1942.

PLAINTIFFS' EXHIBITS Nos. 10, 11, and 12
(Combined and Abridged)

PLAINTIFFS' INTERROGATORIES PROPOUNDED TO DEFENDANT AND ANSWERS

Now Come the plaintiffs, pursuant to Rule 33 of the Federal Rules of Civil Procedure, and propound the following interrogatories to be answered under oath by the corporate defendant by its officer or officers having knowledge of the facts, and with reference to each of said interrogatories the time period inquired of is the time period preceding the filing of the Bill of Complaint herein and subsequent to the dates of issue of the respective patents in suit herein.

1.

Is Plaintiffs' Exhibit 6 a folder published and distributed by or on behalf of the defendant?

Answer: Yes.

2.

Does Plaintiffs' Exhibit 6 correctly describe and illustrate those methods and apparatus, or any of them, admitted in Paragraph IX of the answer herein to have been employed by defendant for

(a) measuring the location of obstructions in wells;

Answer: Yes.

(b) determining in oil wells the fluid density;

Answer: No. The Exhibit No. 6 referred to

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

does not describe how to determine fluid density in oil wells.

(c) determining in oil wells the fluid pressure; and

Answer: Yes.

(d) determining the production capacity of oil wells?

Answer: Yes.

3.

If the answer to Interrogatory 2 is "no", with respect to any of the items (a), (b), (c) or (d), state in what manner the apparatus and methods used by defendant with respect to said "no" answer differs from the respective methods and apparatus described and illustrated therefor in Exhibit 6.

Answer: Exhibit No. 6 referred to does not describe how to determine item (b) of Interrogatory No. 2 and defendant does not know what methods and apparatus were actually used to determine item (b) of Interrogatory No. 2 in the few cases where such item has been determined. See answer to Interrogatory No. 4.

4.

If the answer to Interrogatory 2 is "no" with respect to any of the items (a), (b), (c) or (d), furnish to plaintiffs detailed description and drawings illustrating the method and apparatus employed to perform any of the items to which a "no" answer is made to Interrogatory 2.

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

Answer: Defendant does not know. As stated in the Answer filed herein (and in the Amended Answer), defendant admits that in a few isolated instances employees of defendant have determined fluid density or fluid gradient as, for example, in plaintiffs' Exhibits Nos. 8-A, 8-B, 8-C, 8-D and 9 herein. The practice has long since been discontinued and the records of defendant do not show what methods and apparatus were used. Defendant is informed and believes that such determinations were made only by J. H. Show, formerly an employee of defendant, now believed to be employed by the Division of Oil and Gas, State of California, 629 South Hill Street, Los Angeles, California.

5.

Are the methods and apparatus employed by defendant for locating obstructions in wells, as admitted in Paragraph IX of defendant's answer herein, correctly described and illustrated in the first five pages of the folder, Plaintiffs' Exhibit 6 herein?

Answer: Yes.

6.

If the answer to Interrogatory 5 is "no", furnish to the plaintiffs.

(a) a detailed description of and drawings illustrating the apparatus used and the manner in which it operates for

(1) creating the steep front sound wave;

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued).

(2) communicating said sound wave to the annular space between the tubing and the casing of a well;

(3) how the reflections from the obstructions are received and recorded;

(4) how the recorder tape is driven relative to the pen;

(5) how the filter operates and how it is adjusted to aid or suppress different frequencies.

Answer: Requires no answer.

7.

State whether or not the microphone, amplifier or recorder, or any of them, used by defendant is employed to secure clear records of the echoes from the tubing collars in a well and to suppress or eliminate other disturbances or noises.

Answer: Yes. Echoes of whatever nature in the well are recorded but the arrangement is such that external noises and disturbances are eliminated to a large extent. For example, striking the pipe with a hammer has little or no effect upon defendant's record.

8.

Are the records appearing on the fourth and fifth pages of the folder, Exhibit 6, correct examples of the records made by defendant on actual fluid level measurements made on wells?

Answer: Upon information and belief, yes. The

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

records and the entire Exhibit No. 6 were prepared by Dan Elam, now in the Army. It is possible that the records were slightly touched up before printing. The originals have not been located. The records in Exhibit No. 6 are believed to be correctly illustrative of defendant's actual fluid level measurements.

9.

If the answer to Interrogatory 8 is "no", state how the actual records differ therefrom and furnish typical true actual records or true copies of actual records showing

(a) the shot, tubing collar echoes, tubing catcher echo and fluid level echo;

(b) the shot, a "calibration reflection" and fluid level reflection.

Answer: In view of the fact that the answer to Interrogatory No. 8 is not positive, typical, true, actual records are attached hereto (Plaintiffs' Exhibits 11-A and 11-B). 11-A gives the information called for in item (a) of Interrogatory No. 9 and Exhibit 11-B gives the information called for in item (b) of Interrogatory No. 9.

10.

Does the defendant employ any means for filtering out noises or other disturbances differing in frequency or time period of reception at the microphone of the echoes from successive tubing collars in the well?

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

Answer: Yes, occasionally. Some of defendant's equipment in the field does not have filtering means. Other equipment has filtering means, but even then the filtering means is not always used.

11.

If the answer to Interrogatory 10 is "yes", describe in detail each and every method and apparatus the defendant employs to filter out said noises or other disturbances differing in frequency or time period and reception at the microphone of the echoes from successive tubing collars in the well.

Answer: The filter defendant employs is a conventional electrical system. Since the construction and operation of the filter may not be clear without the description of the entire electrical recording apparatus, a copy of defendant's Echo-Meter Field Manual accompanies these answers (Plaintiffs' Exhibit 11-C). In Exhibit 11-C, the filter circuit is shown on drawing No. 7506. The construction and operation is correctly and fully described in Exhibit 11-C, particularly beginning on page 13 thereof.

12.

If the answer to Interrogatory 10 is "no", describe how and by what apparatus records like Record 2 on Page 4 of Exhibit 6 are obtained by the defendant to show individual tubing collar echoes substantially undisturbed by other noises or frequencies.

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

Answer: Since the answer to Interrogatory No. 10 is partly in the negative, defendant answers Interrogatory No. 12 by stating that often there is not a great deal of difference between the record obtained when a filter is used and the record obtained when the filter is not used. The difference lies chiefly in the shape of the wave on the record. The apparatus employed and the method employed by defendant in obtaining records where no filter is employed consists merely of a hot wire microphone, an electrical amplifier and an electrical recorder, all as described in detail in Exhibit 11-C. The system excludes only noises external to the well. There is nothing which causes tubing collar reflections to be selected and recorded as distinguished from echoes from other obstructions in the well.

13.

Attached hereto is a drawing (now Plaintiffs' Exhibit 10-A).

(The interrogatory then included a long description of the apparatus shown in the drawing and its operation.)

Does the foregoing description and the sketch, (Exhibit 10-A), correctly describe and illustrate the apparatus employed by the defendant for measuring the location of obstructions in wells and the method employed by the defendant for measuring the location of obstructions in wells?

Answer: No, not accurately.

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

14.

If the answer to Interrogatory 13 is "no", then describe in detail and furnish drawings illustrating the differences between the apparatus and methods which are employed by the defendant and the method and apparatus described in Interrogatory 13.

Answer: A complete description with drawings of defendant's apparatus and method of operation is found in Plaintiffs' Exhibit 11-C.

Supplement to Answer: The drawing (Plaintiffs' Exhibit 10-A) correctly illustrates defendant's Echo-Meter diagrammatically except for the following:

A plug valve should be inserted between the elements 9 and 10.

A bleeder valve adapted to connect the interior of the device now marked 10 to the atmosphere, should be added.

A valve should be inserted between the parts marked 7 and 8.

The lead line for the numeral 28 should go to the pipe beneath this numeral, rather than to the valve 29.

The lead line for the numeral 10 should go to a point slightly above that illustrated, the gun being the cylindrical portion above the coupling.

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

The drawing, Plaintiffs' Exhibit 10-A, illustrates diagrammatically a cross section of a typical oil well including casing 1, tubing 2, at the lower end of which is a pump 3, operated by means of sucker rods 4 extending up through the pump tubing 2 and terminating at the upper end as a polished rod 5, to which power mechanism for reciprocating the sucker rods is connected. At the upper end of the casing 1 is a casing head 6, having an opening 7 to which is connected piping 8. Connected to the piping 8 is shown a casing head unit A, of the type illustrated in the second page of the folder, (Plaintiffs' Exhibit 6), this casinghead unit comprising a Y pipe fitting 9, to the vertical branch of which is coupled a gun mechanism 10, in which a cartridge may be located, and fired by an energized electrical solenoid 11 or by a mechanical trigger means. The gun unit A, with the parts identified, is shown in more detail in the attached drawing (Defendant's Exhibit 12-A), and in the attached photographs (Defendant's Exhibits 12-B and 12-C).

To the angle branch of the Y fitting in Plaintiffs' Exhibit 10-A and Plaintiffs' Exhibit 12-A, is coupled a butterfly valve 12 operated by a handle 13, in turn connected to a pipe fitting 14, to which is connected a pressure gauge 15 and an electric connection box 16. Surge chamber 17 comprising a hollow pipe closed at one end, is coupled to the fit-

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

ting 14, and between the surge chamber 17 and the fitting 14 is located a hot wire microphone 18, the construction of which is as illustrated on the drawing No. 7458 of Exhibit 11-C. The grid of the microphone is electrically connected to the connection box or plug 16. An electrical cable 20 extends from the connection box 16 to the transducer in box B, such as illustrated in the upper photograph on page 3 of the folder, Plaintiffs' Exhibit 6.

The transducer apparatus in box B includes an electrical amplifier and an electrical filter. The circuit connections of the amplifier are shown on sheets 1 and 2 (Drawings 7515 and 7531 of Exhibit 11-C). The electrical filter is illustrated on the drawing 7506 of Exhibit 11-C.

In addition to the apparatus illustrated in the drawing, Plaintiffs' Exhibit 10-A, there are several batteries. A 45-volt battery sends an electrical current through the grid of the microphone 18 and heats the same. Automobile batteries supply current to the amplifier and recorder units.

The structure of unit A is such that the firing of the gun or the echoes therefrom cause movement of gas through the grid of the microphone and this movement cools the grid. The grid is of such a nature that its electrical resistance varies with its temperature. Therefore, the electrical resistance of the grid circuit varies when the gun is fired and when the echoes come back from the well, and

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

these changes in resistance control the amount of current in the circuit.

Variations in the electrical current in the heating circuit for the grid of the microphone 18 are amplified by the electrical amplifier in the box B. The electrical amplifier in the box B is connected to an electrical recorder 22 which has a paper tape 23 driven by means of an electric motor at a uniform rate of speed, so that on the tape is recorded, in an amplified form, variations in electrical resistance of the grid of the microphone 18. Hence, the record on the tape 23 shows variations in gas movement through the microphone 18.

A push button 24 is employed to supply electric current through the cable 20 and wires 25 to the solenoid 11 to fire the cartridge in the gun. In some instances electrical firing is not employed and the gun is fired manually by pulling the trigger, or the equivalent on the gun. * * * The attached photograph (marked Exhibit 12-B) shows a mechanically fired gun (a Winchester salute gun). Some elements of the recorder are shown in detail in the drawing marked Plate III of Exhibit 11-C.

The electrical filter in the amplifier circuit in the box B is not always used. When used, it may be tuned to the frequency of tubing collar reflections by a control knob 26. The filter has nothing to do with the sound waves in the well, nor the movement of gas through the microphone 18. It is

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

used to select for the recorder certain electrical impulses passing from the microphone through the electrical amplifier in the box B. By the use of the filter, it is sometimes possible to make a clearer record of tubing collar reflections. The filter does not cause reflections from tubing collars and those from tubing catchers to be distinct. It does not make reflections from tubing catchers or from fluid surfaces any clearer.

The casinghead 6 may be provided with an outlet 27 from which extends a pipe 28, having a valve 29 by which gas within the well may be either prevented from escaping or may be permitted to escape at a desired rate by regulating the valve 29.

The operation of the apparatus is as follows:

The gun 10 is loaded with a blank cartridge, either a 10 gauge shot gun shell or a .38 caliber pistol shell. The selection of the size of cartridge depends upon the distance to the fluid to be located in the well. The approximate distance to the fluid is not always known initially. If it is thought that the fluid is relatively close to the surface, the smaller cartridge is used. If it is found that the fluid is not so close to the surface, the larger cartridge is used on the next shot.

The firing pin of the gun is cocked and held cocked by mechanism which is released upon energization of the firing solenoid 11 or by the trigger, depending upon what type of apparatus is used.

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

The butterfly valve 12 is usually closed while the cartridge is fired, to prevent injury to the microphone 18, especially if the larger cartridge is being fired. The recorder motor is started to move the tape past the recording pen some time prior to the firing of the cartridge. The sound wave created by the firing of the cartridge causes some gas movement in the microphone 18 even when the valve 12 is closed, since the valve 12 is not air tight, so that the firing of the gun is recorded on the tape 23. The sound wave also passes down through the fitting 9 and into the annular space between the tubing 2 and the casing 1, through the opening 7 in the casing head. Successive reflections or echoes from tubing collars 30 cause gas movement through the microphone 18, which operates as described above to make a record on the tape 23 of the echoes from the tubing collars, the position of these echoes on the strip 23 being substantially proportional to the actual successive spacing of the tubing collars on the tubing 2 in the well.

Reflections or echoes from obstructions such as tubing catchers, the top of the liner, if there is a liner in the well, and from the fluid surface, also cause gas movement through the microphone 18 and, accordingly, are indicated on the tape 23, the place on the tape where such records are made being substantially proportional to the actual spacing of these obstructions in the well.

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

The filter is never used on the first shot in a well. The record of the first shot shows the tubing collar reflections, but sometimes they may be made clearer. To make a better record, two things may be done. The filter may be connected into the circuit. The amplifier may be manipulated to increase the strength of the current supplied to the recorder. The selection of the filter setting is determined as follows:

Each Echo-Meter unit has its own electrical characteristics. Each well upon which it is used has its own characteristics, such as the kind of gas, the pressure of the gas, etc. Each Echo-Meter unit is calibrated and from the calibration chart, the operator can determine the setting of the dial 26 on the basis of data about the particular well obtained when the first shot is fired. A calibration chart for one Echo-Meter unit is attached hereto (now Exhibit 12-E).

If the operator desires to improve the record of tubing collar reflections, the dial 26 is set at the point indicated by the calibration chart for the frequency of tubing collar reflections recorded when the filter was not used. A series of records, each with a different adjustment of the knob 26, is never made. Where the filter is used at all, the position of the knob 26 depends only upon the calibration chart and the distance between tubing collar echo records obtained when the first (unfiltered) shot was fired.

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

The second step taken to improve the record of tubing collar reflections is to control the amount of amplification. This may be done during the making of the record. That is, the amount of amplification. (entirely independent from the filter circuit and knob 26) may be increased as the echoes from the well are being received. It may take several seconds for the echoes to return from the well and during this interval, the knob which controls the amplification may be moved manually, gradually, to increase the amplification. In this way the weak echoes from the deeper part of the well may be made to show up as well as the stronger echoes from the collars or obstructions nearer the surface.

15.

Does the defendant count the number of tubing collar echoes or reflections recorded upon the record tape between the record of the shot and the record of the fluid level reflection to determine the location of the fluid level?

Answer: Yes.

16.

Does the defendant measure the length of the record between the record of the shot and the record of the reflection from an obstruction, the location of which is known, and compare this length of record with the length of the record between the rec-

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

ord of the shot and the record of a reflection from an obstruction, the location of which is unknown, to determine the location of the unknown obstruction?

Answer: Yes, at times.

17.

State what compensation, if any, is made

(a) for the variation in the velocity of sound waves in one well under measurement from the velocity of sound waves in another well under measurement; and

Answer: None.

(b) for the average length of tubing sections in one well under measurement being different from the average length of the tubing sections in another well under measurement.

Answer: None.

18.

Has the defendant ever employed pipe connection between the casinghead of a well and the microphone of different lengths?

Answer: No.

19.

If the answer to Interrogatory 18 is in the affirmative, state the reasons for using such different lengths of pipe connections.

Answer: Requires no answer.

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

20.

Has the defendant ever used surge chambers such as that appearing at the left-hand side of the left-hand photograph on page 2 of the folder, Exhibit 6, of different lengths?

Answer: No, not on any one well. However, the surge chambers on defendant's different apparatuses are not always of identical length.

21.

If the answer to Interrogatory 20 is in the affirmative, state the reason for using surge chambers of different length.

Answer: The surge chambers on the different apparatuses are not identical. The variation in length of surge chambers was due merely to happenstance.

22.

Has the defendant ever placed a calibrating reflector in a well at a known location and then in making a fluid level measurement recorded the reflection from the calibrating reflector and the fluid level?

Answer: Yes, a few times. An object has been lowered in a well on a cable to a known location and used as a marker to locate depth of fluid.

23.

Is the printed sheet (now Plaintiffs' Exhibit 7)

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

herein a publication published and distributed by or on behalf of the defendant?

Answer: Yes.

24.

Does Exhibit 7 correctly describe and illustrate those methods and apparatus, or any of them, admitted in Paragraph IX of the answer herein to have been employed by defendant for

(a) measuring the location of obstructions in wells;

Answer: Yes.

(b) determining in oil wells the fluid density;

Answer: No.

(c) determining in oil wells the fluid pressure; and

Answer: Yes.

(d) determining the production capacity of oil wells?

Answer: Yes. See answer to Interrogatory No. 2.

25.

If the answer to Interrogatory 24 is "no", with respect to any of the items (a), (b), (c) or (d), state in what manner the apparatus and methods used by defendant with respect to said "no" answer differs from the respective methods and apparatus described and illustrated therefor in Exhibit 7.

Answer: See answer to Interrogatory No. 3.

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

26.

If the answer to Interrogatory 24 is "no" with respect to any of the items (a), (b), (c) or (d), furnish to plantiffs detailed description and drawings illustrating the method and apparatus employed to perform any of the items to which a "no" answer is made to Interrogatory 24.

Answer: See answer to Interrogatory No. 4.

27.

Are the record sheets, (now Plaintiffs' Exhibit 8-A, 8-B, 8-C, 8-D, and 9) copies of actual records made by the defendant?

Answer: Yes.

28.

Each of the sheets of the records, Plaintiffs' Exhibits 8-A, 8-B, 8-C, 8-D, and 9, are signed "J. H. Show". State whether or not J. H. Show was on or about November 19-25, 1940 employed by defendant and engaged in making fluid level measurements, sub-surface pressure determinations, bottom hole pressure determinations, production capacity determinations, well potential determinations and productivity index determinations of the character admitted in Paragraphs IX and XI of defendant's answer herein.

Answer: Yes.

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

29.

Are the methods of

(a) determining sub-surface pressures;

(b) determining bottom hole pressures;

(c) determining production capacities;

(d) determining well potenials;

(e) determining the productivity index of oil wells; or any of them, admitted to have been performed by defendant in Paragraph IX and XI of the defendant's answer herein, accurately described in Pages 5 through 9 of the folder, plaintiffs' Exhibit 6?

Answer: Yes. See also Plaintiffs' Exhibit 11-C.

30.

If the answer to Interrogatory 29 is "no" with respect to any of the items (a), (b), (c), (d) or (e), furnish to the plaintiffs detailed descriptions and drawings illustrating the methods and apparatus employed to perform any of the items to which a "no" answer is made to Interrogatory 29.

Answer: Requires no answer.

31.

In determining the density of the standing column of fluid in a well, state which of the following steps is used by the defendant and which of said steps is not used by the defendant:

(a) measuring the fluid level of the column under one condition of gas pressure in the casing;

Plaintiffs' Exhibits Nos. 10, 11 and 12
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(b) changing the pressure of gas within the casing to move the surface of the fluid column to a different level;

(c) measuring the new level of the fluid column; and

(d) dividing the change in pressure on the fluid surface required to achieve the new level by the difference in height between the two levels.

Answer: Defendant does not know what steps were employed where density has been determined by employees of defendant. See answer to Interrogatories Nos. 3 and 4.

32.

If the answer to any subdivision of Interrogatory 31 is in the negative, describe the differences between the step or steps employed by defendant for determining the density of the standing column of fluid in a well from that set forth in the subdivision of Interrogatory 31 negatively answered.

Answer: Defendant does not know. See answer to Interrogatory No. 31.

33.

In determining the density of fluid in a well having a casing and a pump suspended therein on tubing, and without requiring the removal of pump parts, which of the following steps is used by the defendant and which of said steps is not used by defendant:

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

(a) determining the fluid level in the annular space between the pump tubing and the casing under one condition of gas pressure;

(b) changing the pressure of gas within the well to move the fluid surface to a new level;

(c) measuring the new level; and

(d) dividing the change in pressure on the fluid surface required to achieve the new level by the difference between the two levels?

Answer: Defendant does not know. See answer to Interrogatory No. 31.

34.

If the answer to any subdivision of Interrogatory 33 is in the negative, then describe the difference between the step or steps employed by defendant for determining the density of the fluid in a well from that set forth in the subdivision of Interrogatory 33 which is negatively answered.

Answer: Defendant does not know. See answer to Interrogatory No. 31.

35.

In the defendant's method of determining the density of the standing column of fluid in a well having a casing and a pump suspended therein, state which of the following steps is used by the defendant and state which of the following steps are not used by the defendant:

(a) measuring the level of the standing column

Plaintiffs' Exhibits Nos. 10, 11 and 12
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of fluid in the well while the pump therein is operated at a given rate of production and under a known condition of gas pressure on the surface of the fluid column;

(b) changing the gas pressure on the fluid column;

(c) continuing the operation of the pump at the same production rate until the level of the standing column becomes stable at a new location;

(d) measuring the new level; and

(e) comparing the difference in the two pressures exerted on the fluid surface at the two levels with the difference in height of the two levels?

Answer: Defendant does not know. See answer to Interrogatory No. 31.

36.

If the answer to any subdivision of Interrogatory 35 is in the negative, describe in detail the difference between the step or steps employed by defendant for determining the density of the standing column of fluid in a well from that set forth in the subdivision of Interrogatory 35 negatively answered.

Answer: Defendant does not know. See answer to Interrogatory No. 31.

37.

In the defendant's method of determining the density of the standing column of fluid in a well

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(Combined and Abridged)—(Continued)

having a casing and a pump suspended therein, state which of the following steps is used by the defendant and state which of the following steps are not used by the defendant:

(a) measuring the stable level of the surface of the standing column of fluid under one condition of pressure of gas released by the well;

(b) measuring the pressure on the fluid surface under said one condition of gas pressure;

(c) regulating the flow of gas from the well to increase the pressure of said gas to a different value to depress the surface of said standing column to a new stable level;

(d) measuring the new level;

(e) measuring the pressure on the fluid surface at the new level; and

(f) comparing the difference in the pressure exerted upon the fluid surface under the two conditions of gas pressure with the difference in height of the levels of the fluid surface under the two pressure conditions.

Answer: Defendant does not know. See answer to Interrogatory No. 31.

38.

If the answer to any subdivision of Interrogatory 37 is in the negative, describe in detail the difference between the step or steps employed by defendant for determining the density of the standing column of fluid in a well from that set forth in

Plaintiffs' Exhibits Nos. 10, 11 and 12
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the subdivision of Interrogatory 37 negatively answered.

Answer: Defendant does not know. See answer to Interrogatory No. 31.

39.

In the defendant's method of determining the density of a standing column of fluid in a well having a casing and a pump suspended therein upon pump tubing and without requiring the removal of pump parts, state which of the following steps is used by the defendant and state which of the following steps is not used by the defendant:

(a) operating the pump under one stable condition of gas pressure in the casing until the fluid level becomes stable;

(b) measuring the distance between the casing head and the surface of the fluid under this stable condition;

(c) altering the casing pressure to a new condition;

(d) operating the pump at the same rate of production under the new condition of gas pressure to again stabilize the fluid level;

(e) measuring the distance between the casing head and the new level of the fluid surface under said new stable condition; and

(f) measuring the casinghead pressures under the two stable conditions.

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Answer: Defendant does not know. See Answer to Interrogatory No. 31.

40.

If the answer to any subdivision of Interrogatory 39 is in the negative, describe in detail the differences between the step or steps employed by the defendant for determining the density of the standing column of fluid in an oil well from that set forth in the subdivision of Interrogatory 39 negatively answered.

Answer: Defendant does not know. See answer to Interrogatory No. 31.

41.

In the defendant's method of determining the pressure exerted in the standing column of fluid in a well at some selected level below the normal surface of the column and without requiring the removal of any of the pump parts, state which of the following steps is used by the defendant and state which of the following steps are not used by the defendant:

(a) measuring the actual stable level of the fluid column under one known condition of gas pressure in the casing;

Answer: Yes.

(b) determining the pressure on the fluid surface at that level;

Answer: No.

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(c) changing the pressure of gas in the well to move the surface of said column to a new actual stable level;

Answer: Yes.

(d) measuring the new level of the fluid surface;

Answer: Yes.

(e) determining the pressure on the fluid surface at the new level;

Answer: No.

(f) determining the density of the fluid by dividing the change in pressure on the fluid surface required to achieve the new level by the difference in height of the two levels; and

Answer: No.

(g) computing the unknown pressure at the desired level by adding to the pressure on the fluid surface at either of the levels the effect in pressure of the column of fluid of the density so determined between the selected actual level and the desired level.

Answer: No.

42.

If the answer to any subdivision of Interrogatory 41 is in the negative, describe in detail the differences between the step or steps employed by the defendant for determining the pressure exerted in the standing column of fluid in a well from that set forth in the subdivision of Interrogatory 41 negatively answered.

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Answer: The method employed by the defendant for determining pressure exerted in the standing column of fluid in a well is described correctly and fully in the manual, Exhibit 11-C, and in Plaintiffs' Exhibit No. 6. The manual, Exhibit 11-C, describes several methods, but distinguishes those used by defendant from other methods.

43.

In the defendant's method of determining the pressure exerted in the standing column of fluid at some selected level below the normal surface of the column and while the pump is operating to remove fluid from the well, state which of the following steps is used by the defendant and state which of the following steps are not used by the defendant:

(a) measuring the actual stable level of the fluid under one known condition of gas pressure in the well by sonic sounding method;

Answer: Yes.

(b) determining the pressure on the fluid surface at that level;

Answer: No.

(c) changing the pressure of the gas in the well to move the surface of the column to a new actual level;

Answer: Yes.

(d) continuing to operate the pump at the same production rate as for the first condition of gas pres-

Plaintiffs' Exhibits Nos. 10, 11 and 12
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sure in the well until the fluid level again becomes stable;

Answer: Yes.

(e) measuring the new stable level and determining the pressure upon the fluid surface at this new level;

Answer: No.

(f) determining the pressure exerted per unit of height of the fluid column by dividing the change in gas pressure on the fluid surface required to effect the change in the fluid level by the difference in height of the two levels; and

Answer: No.

(g) computing the unknown pressure at the selected level by adding to the gas pressure upon the fluid surface at one of the actual levels the effect in pressure of the fluid column between the actual level and the selected level.

Answer: No.

44.

If the answer to any subdivision of Interrogatory 43 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the pressure exerted in the standing column of fluid at some selected level in a well from that set forth in the subdivision of Interrogatory 43 negatively answered.

Answer: See answer to Interrogatory No. 42.

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45.

In the defendant's method of determining the potential production capacity of a well having a casing and a pump suspended therein, state which of the following steps is used by the defendant and state which of the steps are not used by the defendant:

(a) measuring the level of the standing column of fluid in the well at one known rate of production and under one known condition of gas pressure in the well;

Answer: No.

(b) determining the pressure on the surface of the fluid column at that level;

Answer: No.

(c) changing the gas pressure in the well to move the surface of the fluid column to a new level;

Answer: Yes.

(d) measuring the level of the fluid surface under the new gas pressure condition;

Answer: Yes.

(e) determining the pressure on the fluid surface at the new level;

Answer: No.

(f) Dividing the change in pressure on the fluid surface by the difference in height between the two levels to determine the density of the fluid in the column at that rate of production;

Answer: No.

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(g) determining the pressure at some predetermined desired point below the normal fluid surface for that rate of production by adding to the pressure at the fluid surface for either of the measured levels the effect in pressure of the column of fluid between that level and the predetermined desired point;

Answer: No.

(h) changing the rate of production by the pump and repeating the fluid level change and gas pressure determinations to determine the density of the fluid in the column and the pressure of the fluid at some predetermined desired point for the new rate of production;

Answer: No.

(i) dividing the difference in the two production rates by the difference in the corresponding fluid pressures at the desired point; and

Answer: Yes.

(j) using the ratio thus found to determine the maximum rate at which the well is capable of being produced.

Answer: Yes.

46.

If the answer to any subdivision of Interrogatory 45 is in the negative, describe in detail the difference between the step or steps empoyed by the defendant for determining the potential production capacity of a well having a casting and a pump suspended therein from that set forth in the subdivision of Interrogatory 45 negatively answered.

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(Combined and Abridged)—(Continued)

Answer: The steps employed by defendant for determining the potential production capacity of a well having a casing and pump suspended therein, is described correctly and fully in Plaintiffs' Exhibit 11-C.

47.

In the defendant's method of determining the pressure exerted by the well fluid at any point below the normal surface thereof, state which of the following steps is used by the defendant and state which of the following steps are not used by the defendant:

(a) determining the location of the fluid surface under one condition of pressure of gas on the surface;

Answer: No.

(b) determining said gas pressure under said one condition;

Answer: No.

(c) changing the gas pressure to move the fluid surface to a new stable level;

Answer: Yes.

(d) determining the new gas pressure on the fluid surface;

Answer: No.

(e) determining the location of the new surface level; and

Answer: Yes.

(f) comparing the difference in the gas pressures

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with the corresponding change in height of the surface level to determine the relation between them.

Answer: No.

48.

If the answer to any subdivision of Interrogatory 47 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the pressure exerted by the well fluid at any point below the normal surface thereof from that set forth in the subdivision of Interrogatory 47 negatively answered.

Answer: See answer to Interrogatory No. 42.

49.

In the defendant's method of determining the pressure exerted by the well fluid at any point below the surface thereof while a mechanical pump is operating in that well, state which of the following steps is used by the defendant and state which of the following steps are not used by the defendant:

(a) determining the stable location of the fluid surface under one condition of gas pressure in the casing in the well;

Answer: Yes.

(b) determining the gas pressure on the fluid surface at that level;

Answer: No.

(c) changing the pressure of gas in the casing to move the fluid surface to a new stable level;

Answer: Yes.

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(d) determining the new location of the fluid surface;

Answer: Yes.

(e) determining the gas pressure on the surface at the new level; and

Answer: No.

(f) comparing the difference between the pressures on the surface with the corresponding change in height of the fluid surface to determine the relation between changes in pressure on the fluid surface and the corresponding changes in the location of the fluid surface.

Answer: No.

50.

If the answer to any subdivision of Interrogatory 49 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the pressure exerted by the well fluid from that set forth in the subdivision of Interrogatory 49 negatively answered.

Answer: See answer to Interrogatory No. 42.

51.

In the defendant's method of determining the potential production capacity of a well having a casing and a pump suspended therein, state which of the following steps is used by the defendant and state which of the following steps are not used by the defendant:

(a) determining the pressure exerted by the well

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fluid at some selected point below the normal surface thereof under one known rate of production by

(1) determining the location of the fluid surface under one condition of gas pressure on the surface.

(2) determining the gas pressure on the fluid surface under said one condition;

(3) changing the gas pressure to move the fluid surface to a new stable level under the same production rate;

(4) determining the new gas pressure on the fluid surface;

(5) determining the location of the new surface level;

(6) comparing the difference in said gas pressures with the corresponding change in height of the new surface level to ascertain the pressure exerted at said selected point under said one rate of production;

Answer: No. Defendant employs the steps listed in a-3 and a-5, and does not employ the steps listed in a-1, a-2, a-4 and a-6.

(b) changing the rate of production from said well;

Answer: Yes.

(c) repeating the steps of determining the location of the fluid surface at two stable levels and the gas pressures on said surface to maintain said levels under the new production rate to ascertain the pressure exerted at the same selected point; and

Answer: No.

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(d) comparing the difference in production rates with the corresponding difference in pressures at said selected point to determine their relation from which the maximum rate of production from the well may be determined.

Answer: Yes.

52.

If the answer to any subdivision of Interrogatory 51 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the potential production capacity of a well from that set forth in the subdivision of Interrogator 51 negatively answered.

Answer: See answer to Interrogatory No. 46.

53.

In the defendant's method of determining the density of the standing column of fluid in a well, state which of the following steps is used by the defendant and state which of the following steps are not used by the defendant:

(a) measuring the level of the fluid column under one condition of gas pressure;

(b) measuring the gas pressure at the casing head of the well;

(c) changing the gas pressure at the casing head of the well to move the surface of the fluid column to a new level;

(d) measuring the new level; and

(e) comparing the change in gas pressure at the

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casing head with the difference in height between the two levels.

Answer: Defendant does not know. See answer to Interrogatory No. 31.

54.

If the answer to any subdivision of Interrogatory 53 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the density of the standing column of fluid in a well from that set forth in the subdivision of Interrogatory 53 negatively answered.

Answer: Defendant does not know. See answer to Interrogatory No. 31.

55.

In the defendant's method of determining the pressure exerted in the standing column of fluid in the well at some selected level below the normal surface of the column and without requiring the removal of the pump parts, state which of the following steps are used by the defendant and state which of the following steps are not used by the defendant:

(a) measuring the actual level of the fluid surface of the fluid column under one known condition of gas pressure at the casing head;

Answer: In answering Interrogatory No. 55, it should be noted that steps (a), (b) and (d) do not constitute a complete method of determining the

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pressure exerted in the standing column of fluid in the well at some selected level, as called for in the question.

Answer: (a) Yes.

(b) changing the pressure of the gas at the casing head to move the surface of the fluid column to a new actual level;

Answer: (b) Yes.

(c) measuring the new level of the fluid surface; and

Answer: (c) Yes.

(d) comparing the difference in height of the two actual levels with the casing head pressures of gas under which the two levels were measured to determine the casing head pressure which would be required to move the surface of the fluid column to the selected level.

Answer: Yes.

56.

If the answer to Interrogatory 55 is in the affirmative, does defendant make any compensation for the difference between the casinghead pressure and the effect in pressure of the column of gas in the well?

Answer: No. Defendant does not make any compensation for the difference between the casinghead pressure and the effect in pressure of the column of gas in the well. Defendant does compensate for the difference between the effect in pressure of the theoretical column of gas in the well at the

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theoretical casinghead pressure which would be required to move the surface of the liquid column to the selected level, as recited in step (d) of Interrogatory No. 55.

57.

If the answer to Interrogatory 56 is in the affirmative, state how such compensation is made.

Answer: The compensation referred to in the answer to Interrogatory No. 56 is obtained by taking the theoretical casinghead gas pressure and the theoretical height of the column of gas and applying Dice's formula or the equivalent. (For Dice's formula, see page 151 of the publication, Defendant's Exhibit K-3, "Sub-Surface Pressures in Oil Wells and their Field of Application", by D. G. Hawthorne published in 1933, cited in the Answer herein).

58.

If the answer to Interrogatory 55 is in the negative, then describe in detail the differences between the method which is employed by the defendant for determining the pressure exerted in the standing column of fluid in the well at some selected level below the normal surface of the column and without requiring the removal of the pump parts and the method steps set forth in Interrogatory 55.

Answer: See answers to Interrogatories 56 and 57. See also, Exhibit 11-C, which correctly and fully describes the method employed by defendant for de-

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termining the pressure exerted in the standing column of fluid in a well at some selected level.

59.

In the defendant's method of determining the potential capacity of an oil well or the productivity index of an oil well, state which of the following steps are used by the defendant and state which of the following are not used by the defendant:

(a) determining the pressure exerted by the well fluid at the pump under one rate of production of oil from the well by the pump by

(1) measuring the fluid level under one condition of gas pressure in the well;

(2) measuring that one gas pressure in the well;

(3) changing the gas pressure in the well to move the fluid surface to a new level;

(4) measuring the new level of the fluid surface;

(5) measuring the new gas pressure in the well;

(6) comparing the differences in height of the two fluid levels with the difference in the two gas pressures to thereby determine the pressure at the pump;

Answer: No. Defendant determines the gas pressure at the casing head but does not determine the gas pressure in the well. Defendant does not employ the steps enumerated as 2, 5 and 6 of item (a) of Interrogatory No. 59.

(b) changing the rate of production of oil from the well;

Answer: Yes.

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(c) repeating the steps of determining the location of the fluid surface at two levels and the gas pressures in the well required to maintain the said levels under the new production rate and comparing the difference in levels of the fluid surface and the difference in pressures required to maintain them to determine the pressure at the pump under the new production rate; and

Answer: No; same as answer to 59 (a).

(d) comparing the two pressures at the pump with the two production rates to determine the productivity index or potential production capacity of the well.

Answer: Yes.

60.

If the answer to any subdivision of Interrogatory 59 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the potential capacity of an oil well or the productivity index of an oil well from that set forth in the subdivision of Interrogatory 59 negatively answered.

Answer: Defendant's method for determining the potential capacity of a well or the productivity index is correctly and fully described in Exhibit 11-C.

61.

Is the chart, Fig. 1 on Page 6 of the folder, Plaintiff's Exhibit 6, a correct representation of the manner in which defendant utilizes fluid level mea-

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surements and gas pressure measurements to determine the fluid pressure at the pump under two different rates of production of fluid from the well?

Answer: Yes.

62.

If the answer to Interrogatory 61 is in the negative, then furnish a chart used by defendant which does correctly set forth the information recited in the Interrogatory 61 and describe in detail the difrences between the chart furnished and the chart referred to in Interrogatory 61.

Answer: Requires no answer.

63.

In the defendant's method of determining the unknown location of an obstruction in a well having a string of tubing therein constructed of a plurality of lengths of tubing connected to each other by couplings, state which of the following steps are used by the defendant and state which of the following steps are not used by the defendant:

(a) creating a pressure impulse in the annular space between the tubing and the casing of the well;

Answer: No.

(b) registering the echoes from the tubing collars and from the obstruction of unknown location; and

Answer: Yes.

(c) counting the tubing collar echoes occurring between the creation of the pressure impulse and the

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

echo from the obstruction of unknown location to determine the location of the obstruction of unknown location.

Answer: No.

64.

If the answer to any subdivision of Interrogatory 63 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the unknown location of an obstruction in a well having a string of tubing therein from that set forth in the subdivision of Interrogatory 63 negatively answered.

Answer: The method employed by defendant for determining the unknown location of an obstruction (fluid level) in a well is correctly and fully described in Plaintiffs' Exhibit 6 and in Exhibit 11-C. Defendant does not employ apparatus for creatng a pressure impulse but employs apparatus for making a sound.

65.

Attached hereto (Exhibit 10-B) is a copy of nine strips of record tape, each bearing the name "Echometer Service", "Cities Service Oil"; state whether or not Exhibit 10-B is a true copy of the record charts made by the defendant at the Cities Service Oil Company Lease Ray B Wall No. 2, on the dates and times indicated on Exhibit 10-B.

Answer: Yes, but the date is subsequent to the filing of the Complaint herein.

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

66.

On the record charts shown in Exhibit 10-B are notations "10", "20", "30", "40", "34.8", "40.9", "49.35", and similar markings beside the peaks of the record chart; state whether or not it is ever the practice of the defendant or its employees to place such markings on the record charts produced by the defendant.

Answer: Yes.

67.

If the answer to Interrogatory 66 is in the affirmative, state what those notations "10", "20", "30", etc. mean.

Answer: The numerals 10, 20, 30, etc. referred to are counts by the operator of the number of reflections from collars of tubing.

68.

Attached hereto (Exhibit 10-C) is a copy of six strips of record tape, each bearing the name "Echometer Service", "Phillips Petro. Co."; state whether or not Exhibit 10-C is a true copy of the record charts made by the defendant at the Phillips Petroleum Co. Lease Kraft, Well No. 3, on the dates and times indicated on Exhibit 10-C.

Answer: Yes.

69.

On the record charts shown in Exhibit 10-C are notations "41^0", "51^4", "37^2", "36^8", "31^2" and

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

"31" beside the peaks of the record chart; state whether or not it is ever the practice of the defendant or its employees to place such markings on the record charts produced by the defendant.

Answer: Yes.

70.

If the answer to Interrogatory 69 is in the affirmative, state what those notations "41^0", "41^4", etc. mean.

Answer: Same as answer to Interrogatory No. 67.

71.

In the defendant's method of determining the unknown location of an obstruction in a well having a string of tubing therein, state which of the following steps are used by the defendant and state which of the following steps are not used by the defendant:

(a) creating an acoustical impulse in the annular space between the tubing and the well casing to produce echoes from portions of the tubing string distinguishable from each other and from the echo from the unknown obstruction;

Answer: No. Defendant creates an acoustical wave but not an impulse in the annular space. The acoustical wave does not produce distinguishable echoes as stated in Interrogatory 71 (a).

(b) observing the lapse of time between the arrival at a predetermined point of the echoes from successive portions of the tubing string to thereby

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

determine the velocity of the pressure wave through the particular well under measurement; and

Answer: No.

(c) measuring the lapse of time between the creating of the pressure impulse and the arrival at some predetermined point of the echo from the unknown obstruction.

Answer: No.

72.

If the answer to any subdivision of Interrogatory 71 is in the negative, describe the difference between the step or steps employed by the defendant for determining the unknown location of an obstruction in a well having a string of tubing therein from that set forth in the subdivision of Interrogatory 71 negatively answered.

Answer: The defendant's method referred to is correctly and fully described in Plaintiffs' Exhibit 6, and Exhibit 11-C.

73.

In the defendant's method of determining the unknown location of an obstruction in a well having a string of tubing therein, state which of the following steps are used by the defendant and state which of the following steps are not used by the defendant:

(a) creating an acoustical impulse in the annular space between the tubing and the well casing of such magnitude as compared with the depth of the well and the resistance to pressure wave transmission therethrough as will produce echoes from por-

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

tions of the tubing string distinguishable from each other and from the echo from the unknown obstruction;

Answer: No.

(b) observing the lapse of time between the arrival at a predetermined point of the echo from successive portions of the tubing string to thereby determine the velocity of the pressure wave through the particular well under measurement; and

Answer: No.

(c) measuring the lapse of time between the creating of the pressure impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

Answer: No.

74.

If the answer to any subdivision of Interrogatory 73 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the unknown location of an obstruction in a well having a string of tubing therein from that set forth in the subdivision of Interrogatory 73 negatively answered.

Answer: See answer to Interrogatory No. 72.

75.

In the defendant's method of determining the unknown location of an obstruction in a well having a casing with tubing therein restricting the volume of the annular space within the casing and

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

having another obstruction therein at a know location above the unknown obstruction, state which of the following steps are used by the defendant and state which of the following steps are not used by the defendant:

(a) creating in the annular space an acoustical impulse to produce echoes from different obstructions distinguishable from each other;

Answer: No.

(b) observing the lapse of time between the creation of the impulse and the arrival at a predetermined point of the echo from the unknown obstruction; and

Answer: No.

(c) comparing with said time lapse the time lapse between the creation of the impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

Answer: No.

76.

If the answer to any subdivision of Interrogatory 75 is in the negative, describe the difference between the step or steps employed by the defendant for determining the unknown location of an obstruction in a well from that set forth in the subdivision of Interrogatory 75 negatively answered.

Answer: See answer to Interrogatory No. 72.

77.

In the defendant's method of determining the unknown location of an obstruction in a well hav-

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

ing a casing with tubing therein restricting the volume of the annular space within the casing and having another obstruction therein at a known location above the unknown obstruction, state which of the following steps are used by the defendant and state which of the following steps are not used by the defendant:

(a) creating in the annular space an acoustical impulse of such magnitude as compared with the depth of the well and the resistance to pressure wave transmission therethrough as will produce echoes from different obstructions distinguishable from each other;

Answer: No.

(b) observing the lapse of time between the creation of the impulse and the arrival at a predetermined point of the echo from the unknown obstruction; and

Answer: No.

(c) measuring the lapse of time between the creation of the impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

Answer: No.

78.

If the answer to any subdivision of Interrogatory 77 is in the negative, describe the difference between the step or steps employed by the defendant for determining the unknown location of an obstruction in a well from that set forth in the sub-

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

division of Interrogatory 77 negatively answered.

Answer: See answer to Interrogatory No. 72.

79.

In the defendant's method of determining the unknown location of an obstruction in a well, state which of the following steps are used by the defendant and state which of the following steps are not used by the defendant:

(a) placing another obstruction in the well at a known depth in the well;

Answer: Yes, occasionally. See answer to Interrogatory No. 22.

(b) creating a pressure impulse in the well;

Answer: No.

(c) observing the lapse of time between the creation of the pressure impulse and the arrival at a predetermined point of the echo thereof from the obstruction of known location; and

Answer: No.

(d) measuring the lapse of time between the creation of the pressure impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

Answer: No.

80.

If the answer to any subdivision of Interrogatory 79 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the unknown location of an obstruction in a well from that set forth in

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

the subdivision of Interrogatory 79 negatively answered.

Answer: See answer to Interrogatory No. 72.

81.

In the defendant's method of determining the unknown location of an obstruction in a well having a casing with tubing therein restricting the volume of the annular space within the casing and having an approximately known depth and a known pressure of gas within said space from which the approximate magnitude of acoustical impulse required to traverse the restricted space and produce echoes from the several obstructions in the well may be estimated, state which of the following steps are used by the defendant and which of the following steps are not used by the defendant:

(a) introducing into said space between the casing and the tubing a series of acoustical impulses, each of different magnitude approximating the estimated magnitude to produce from each impulse echoes from the different obstructions in the well;

Answer: No.

(b) observing the echoes that are produced by each impulse to select the one that produces distinguishable echoes from each of the obstructions in the well; and

Answer: No.

(c) recording the echoes of an impulse of the selected magnitude in the relative times and order

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

in which they are received at the ground surface.

Answer: No.

In answer to this interrogatory, defendant states further that the introductory portion of Interrogatory No. 81 does not define the objects of defendant's method. Defendant does not care to know the "approximately known depth and known pressure of gas" within the annular space, and makes no estimate of the magnitude of an impulse which would be required to traverse the restricted space.

82.

If the answer to any subdivision of Interrogatory 81 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the unknown location of an obstruction in a well from that set forth in the subdivision of Interrogatory 81 negatively answered.

Answer: See answer to Interrogatory No. 72.

83.

In the defendant's method of determining the unknown location of an obstruction in a well having a string of pipe therein consisting of sections of known mean length connected by couplings, state which of the following steps are used by defendant:

(a) creating an impulse in the well adapted to produce an echo from each of a plurality of suc-

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

cessive couplings and from the obstruction of unknown location;

Answer: No.

(b) sequentially registering the impulse and such echoes in spaced relation to each other proportional to the actual relative spacing of the coupling and the unknown obstruction; and

Answer: No.

(c) computing the distance to the unknown obstruction from said known mean length between successive couplings and the number of registered coupling echoes.

Answer: Yes.

84.

If the answer to any subdivision of Interrogatory 83 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the unknown location of an obstruction in a well having a string of pipe therein from that set forth in the subdivision of Interrogatory 83 negatively answered.

Answer: See answer to Interrogatory No. 72.

85.

In the defendant's method of determining the distance to an unknown location of an obstruction in a well having a casing with tubing therein restricting the volume of the annular space within the casing and having another obstruction therein at a known location, state which of the following steps are not used by defendant and which of the following steps are used by defendant:

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

(a) creating at some known point within the casing an impulse to produce echoes from said obstructions distinguishable from each other;

Answer: No.

(b) sequentially registering the impulse and the echoes from said obstructions in spaced relation to each other; and

Answer: No.

(c) determining the distance to the unknown obstruction from said known point of impulse by comparing the elapsed time between the registrations of the impulse and the echo from the known obstruction with the elapsed time between the registrations of the impulse and the echo from the unknown obstruction.

Answer: No. In answer to item (c) of Interrogatory No. 85, defendant states that it computes the distance to the obstruction (fluid level) by multiplying the number of joints of tubing by the length of each joint, obtaining the answer directly in feet, instead of computing the elapsed time.

86.

If the answer to any subdivision of Interrogatory 85 is in the negative, describe in detail the difference between the step or steps employed by the defendant for determining the distance to an unknown location of an obstruction in a well from that set forth in the subdivision of Interrogatory 85 negatively answered.

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

Answer: See answer to Interrogatory No. 72.

87.

In the defendant's method of determining the location of an obstruction in a well, state which of the following pieces of apparatus are used by the defendant and state which pieces of said apparatus are not used by the defendant:

(a) means communicating with the well for creating a pressure impulse in the well;

Answer: No.

(b) echo receiving means including a pressure responsive device exposed to the well for receiving pressure impulses from the well and for measuring the lapse of time between the creation of the impulse and the arrival at the receiving means of the echo from the obstruction; and

Answer: No.

(c) means associated with the pressure responsive device for tuning the receiving means to the frequency of echoes from the tubing collars of tubing sections of the well to clearly distinguish the echoes from the couplings from each other.

Answer: No.

88.

If the answer to any subdivision of Interrogatory 87 is in the negative, describe in detail the difference between the apparatus employed by the defendant for determining the location of an obstruction in a well from that set forth in the subdivision of Interrogatory 87 negatively answered.

Answer: See answer to Interrogatory No. 72.

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

89.

In the defendant's method of determining the location of an obstruction in a well, state which of the following pieces of apparatus are used by the defendant and state which of said pieces of apparatus are not used by the defendant;

(a) means communicating with the well for creating a pressure impulse in the well;

Answer: No.

(b) a pressure responsive device for receiving pressure impulses from the well;

Answer: No.

(c) means coupling said pressure responsive device to the well to expose the device to pressure variations existing in the well and having a length approximately a multiple of the length of a tubing section in the well to tune the device to the frequency of the echoes from the impulse received from the couplings of the tubing string; and

Answer: No.

(d) means associated with the device for recording the echoes from the tubing couplings and from the obstruction to permit counting the coupling echoes between the creation of the impulse and the echo from the unknown obstruction to determine its location.

Answer: No.

90.

If the answer to any subdivision of Interrogatory 89 is in the negative, describe in detail the differ-

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

ence between the apparatus employed by the defendant for determining the location of an obstruction in a well from that set forth in the subdivision of Interrogatory 89 negatively answered.

Answer: See answer to Interrogatory No. 72.

91.

In the defendant's method of locating an obstruction in a well, state which of the following pieces of apparatus are used by the defendant and which of said pieces of apparatus are not used by the defendant:

(a) means communicating with the well for creating a pressure impulse in the well to produce echoes of the impulse from the tubing couplings and other obstructions in the well;

Answer: No.

(b) echo receiving and registering means coupled to the well to expose the receiving and registering means to pressure variations produced in the well by echoes from the obstructions; and

Answer: No.

(c) means associated with the receiving and registering means to accent the registration of tubing coupling echoes.

Answer: No.

92.

If the answer to any subdivision of Interrogatory 91 is in the negative, describe in detail the difference between the apparatus employed by the de-

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

fendant for determining the location of obstructions in wells from that set forth in the subdivision of Interrogatory 91 negatively answered.

Answer: See answer to Interrogatory No. 72.

93.

In the defendant's method for determining the unknown location of an obstruction in a well, state which of the following pieces of apparatus are used by the defendant and which of the following pieces of apparatus are not used by the defendant:

(a) means communicating with the well for creating a pressure impulse in the well to produce echoes of the impulse from tubing couplings and other obstructions in the well;

Answer: No.

(b) pressure responsive echo receiving and registering means coupled to the well to expose the receiving and registering means to pressure variations in the well produced by echoes from the obstructions; and

Answer: No.

(c) an interference eliminating means associated with the receiving and registering means for limiting the response of the receiving and registering means to the registration of echoes from actual obstructions in the well.

Answer: No.

94.

If the answer to any subdivision of Interrogatory 93 is in the negative, describe in detail the differ-

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

ence between the apparatus employed by the defendant for determining the unknown location of an obstruction in a well from that set forth in the subdivision of Interrogatory 93 negatively answered.

Answer: See answer to Interrogatory No. 72.

95.

In the defendant's method of determining the unknown location of an obstruction in a well, state which of the following pieces of apparatus are employed by the defendant and which of said pieces of apparatus are not employed by the defendant:

(a) means communicating with the well for creating a pressure impulse in the well to produce echoes of said impulse from the tubing couplings and other obstructions in the well;

Answer: No.

(b) pressure responsive echo receiving and registering means coupled to the well to expose the receiving and registering means to the pressure variations produced in the well by echoes from the obstructions; and

Answer: No.

(c) resonance means associated with said receiving and registering means to produce therein a natural acoustical period of oscillation so related to the frequency of the echoes from the tubing couplings as to accent the registration of the tubing coupling echoes.

Answer: No.

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

96.

If the answer to any subdivision of Interrogatory 95 is in the negative, describe in detail the difference between the apparatus employed by the defendant for determining the unknown location of an obstruction in a well from that set forth in the subdivision of Interrogatory 95 negatively answered.

Answer: See answer to Interrogatory No. 72.

97.

In the defendant's method of determining the unknown location of an obstruction in a well, state which of the following pieces of apparatus are used by the defendant and which of said pieces of apparatus are not used by the defendant:

(a) means communicating with the well for creating therein a pressure impulse to produce echoes of the impulse from the tubing couplings and other obstructions in the well;

Answer: No.

(b) echo receiving and registering means including a pressure responsive device and pipe means coupling the pressure responsive device to the well to expose the device to pressure variations in the well; and

Answer: No.

(c) means for adjusting the effective length of the pipe means to produce a natural acoustical period of oscillation of the pressure responsive device so related to the frequency of the echoes from

tubing couplings as to accent the registration of said echoes.

Answer: No.

98.

If the answer to any subdivision of Interrogatory 97 is in the negative, describe in detail the difference between the apparatus employed by the defendant for determining the unknown location of an obstruction in a well from that set forth in the subdivision of Interrogatory 97 negatively answered.

Answer: See answer to Interrogatory No. 72.

99.

In the defendant's method of determining the unknown location of an obstruction in a well, state which of the following pieces of apparatus are employed by the defendant and which of said pieces of apparatus are not employed by defendant:

(a) means communicating with the well for creating therein a pressure impulse to produce echoes of said impulse from the tubing coupling and other obstructions in the well;

Answer: No.

(b) pressure responsive echo receiving and registering means having a natural frequency of oscillation so related to the frequency of echoes from the tubing couplings as to accent the registration of said echoes; and

Answer: No.

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

(c) means interconnecting the receiving and registering means to the well to expose the receiving and registerming means to pressure variations in the well.

Answer: No.

100.

If the answer to any subdivision of Interrogatory 99 is in the negative, describe in detail the difference between the apparatus employed by the defendant for determining the unknown location of an obstruction in a well from that set forth in the subdivision of Interrogatory 99 negatively answered.

Answer: See answer to Interrogatory No. 72.

101.

State whether or not the defendant purchased that part of its business which includes methods and apparatus for determining the location of obstructions in wells, determining fluid density in oil wells, determining fluid pressure in oil wells and determining production capacity in oil wells, as admitted by defendant in Paragraph X of its answer herein, from International Geophysics, Inc. or J. J. Jakosky, or either of them, and if so, which one?

Answer: No. It is not correct to say that defendant purchased that part of its business which includes methods and apparatus for doing the things recited from International Geophysics, Inc. or J. J. Jakosky, or either of them. Defendant began de-

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

veloping sonid fluid level locating apparatus in February, 1938 and had built and tested its own apparatus by the end of July, 1938. At that time defendant had not conducted any negotiations with International Geophysics, Inc. or J. J. Jakosky, looking toward the purchase of any business, apparatus, patents or the like relating to this subject matter. Negotiations were opened about February, 1940 with International Geophysics, Inc. Defendant purchased by a contract made as of the 1st day of May, 1940, the entire "Echo-Meter" business of International Geophysics, Inc., together with equipment, patent rights, good will, etc.

Defendant did not purchase from International Geophysics, Inc. or J. J. Jakosky any apparatus for determining fluid density in oil wells, and defendant did not purchase from anyone methods for doing the things referred to in this interrogatory, the methods defendant uses having already become public property.

102.

State whether or not, at the time defendant acquired that part of its business pertaining to the methods and apparatus admitted to be used by the defendant in Paragraph IX of its answer, any investigation was made of the patent situation relating to said methods, and apparatus to determine whether or not said methods and apparatus would infringe any United States Letters Patent.

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

Answer: No. An investigation of the patent situation relating to the methods and apparatus referred to was first made for defendant in January, 1939. Subsequently, knowledge of the art was kept current, but no new investigation was made at the time of the execution of the agreement with International Geophysics, Inc. in May, 1940 or during the negotiations leading up to the execution of that agreement. However, in May, 1940, defendant was familiar with those patents which had then issued to plaintiffs. (Patent No. 2,209,944 had not yet issued.)

103.

If the answer to Interrogatory 102 is "yes", state whether or not the defendant as a result of such investigation became aware of the existence of the United States Letters Patent in suit herein.

Answer: Requires no answer.

104.

State when the defendant first learned of each of the United States Letters Patent in suit herein.

Answer: Defendant obtained copies of each of the patents here in suit probably within a month after the issuance thereof.

105.

State how the defendant first received knowledge of the existence of each of the United States Letters Patent in suit herein.

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

Answer: An employee of defendant reviews the Official Gazette of the U. S. Patent Office every week, and orders copies of patents which relate to defendant's business. Copies of the letters patent in suit were so noticed, ordered and received.

106.

State whether or not the defendant has ever received from the plaintiff or its representatives any notification, oral or written, charging defendant with infringing any of the Letters Patent in suit.

Answer: No. No written or formal notice of a charge of infringement was received from plaintiffs prior to the filing of the Complaint herein. Prior to the filing of the Complaint, plaintiffs endeavored to sell their fluid level locating business to defendant or reach a "friendly workable agreement" and during negotiations the patents here in suit were extolled, but plaintiffs professed ignorance of the details of what defendant was doing and defendant denies that any notice, either oral or written, was ever given defendant.

107.

On July 6, 1939 a formal notice of infringement of United States Letters Patent Nos. 2,156,519 and 2,161,733 was sent by Plaintiffs to International Geophysics, Inc.; state whether or not the defendant has ever received any knowledge of said notice of infringement and when said knowledge was acquired by defendant.

Plaintiffs' Exhibits Nos. 10, 11 and 12
(Combined and Abridged)—(Continued)

Answer: Defendant is without knowledge as to whether or not a formal notice of infringement of Letters Patent No. 2,156,519 and No. 2,161,733 was sent by plaintiffs to International Geophysics, Inc. on July 6, 1939.

108.

State whether or not, on or about September 16, 1940, Robert P. Miller delivered to Erle P. Halliburton a copy of each of the United States Letters Patent in suit.

Answer: Yes.

109.

State whether or not Erle P. Halliburton is an officer of the defendant corporation.

Answer: Yes.

110.

State whether or not, on or about September 16, 1940, Robert P. Miller notified Erle P. Halliburton orally that the defendant's methods and appartus, admitted in Paragraph IX of the answer herein, were infringements of the United States Letters Patent in suit herein.

Answer: No. Robert P. Miller discussed the patents here in suit with Erle P. Halliburton only in connection with a proposal that defendant purchase the business of the Depthograph Company, or similar proposals.

Plaintiffs' Exhibits Nos. 10, 11 and 12 (Combined and Abridged)—(Continued)

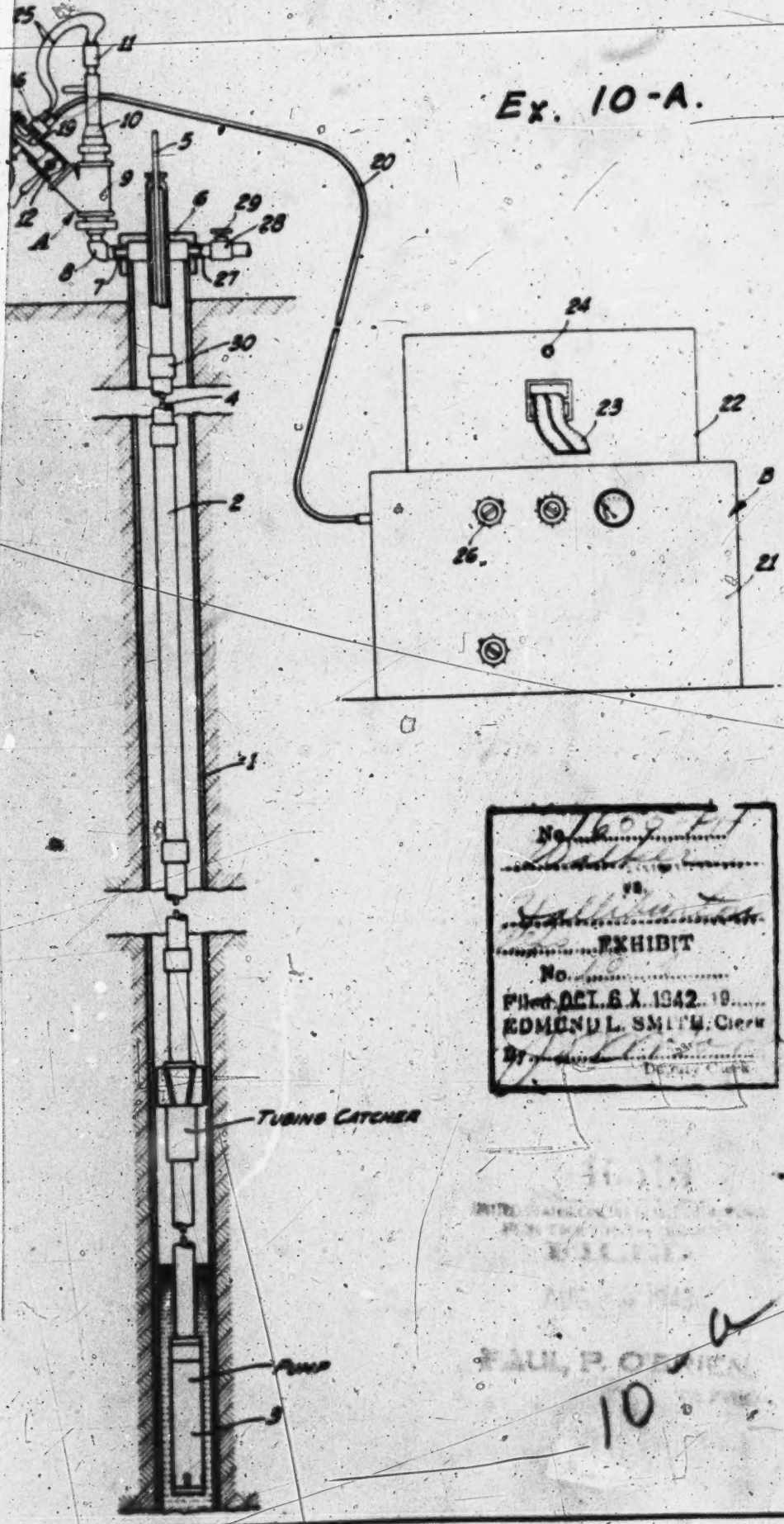
111.

State when the defendant acquired that part of its business which includes the methods and apparatus admitted by the defendant in Paragraph IX of its answer herein.

Answer: Defendant started acquiring the business referred to in February, 1938 by developing sonic fluid level locating apparatus.

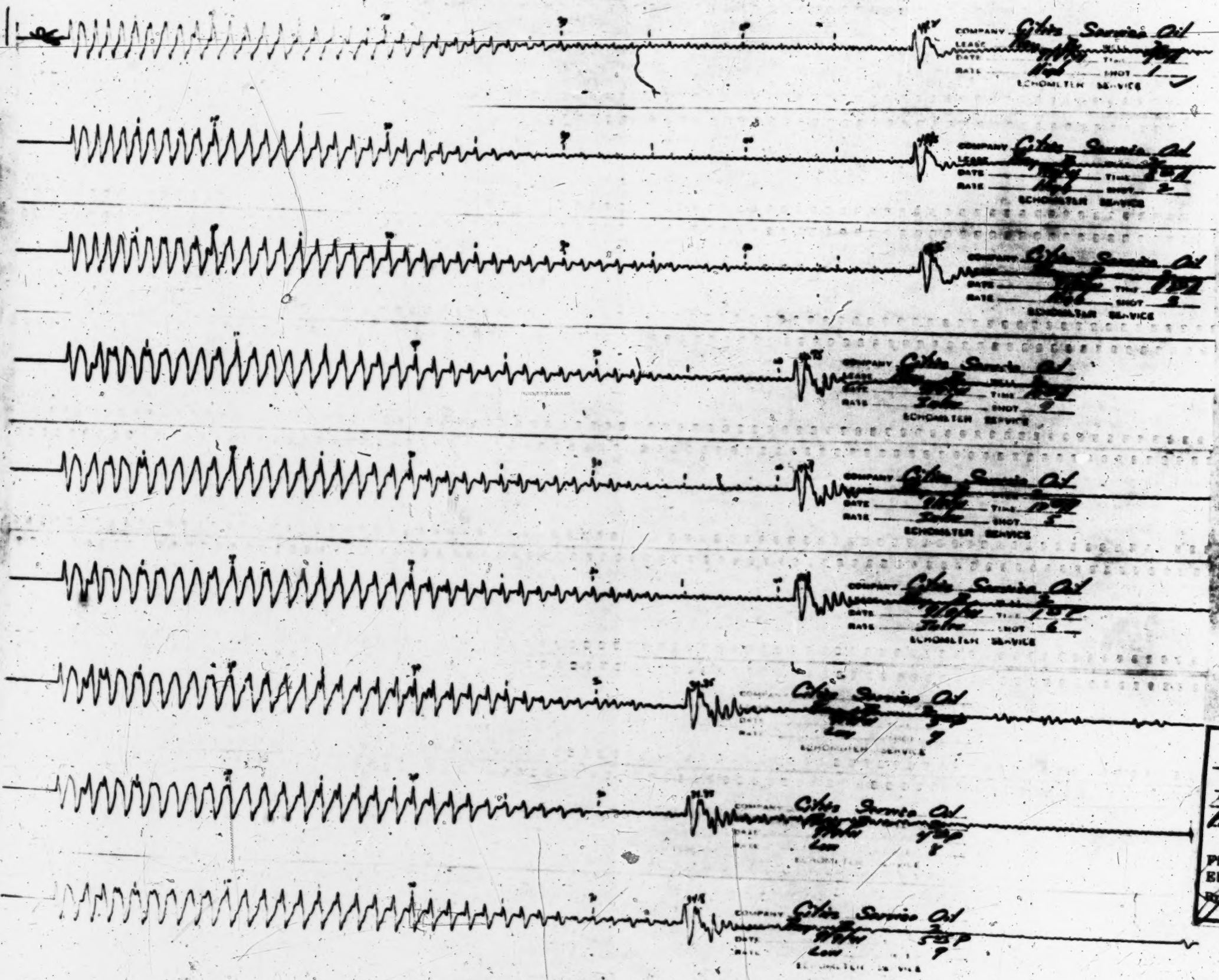
[Endorsed]: Filed June 1, 1943.

Ex. 10-A.



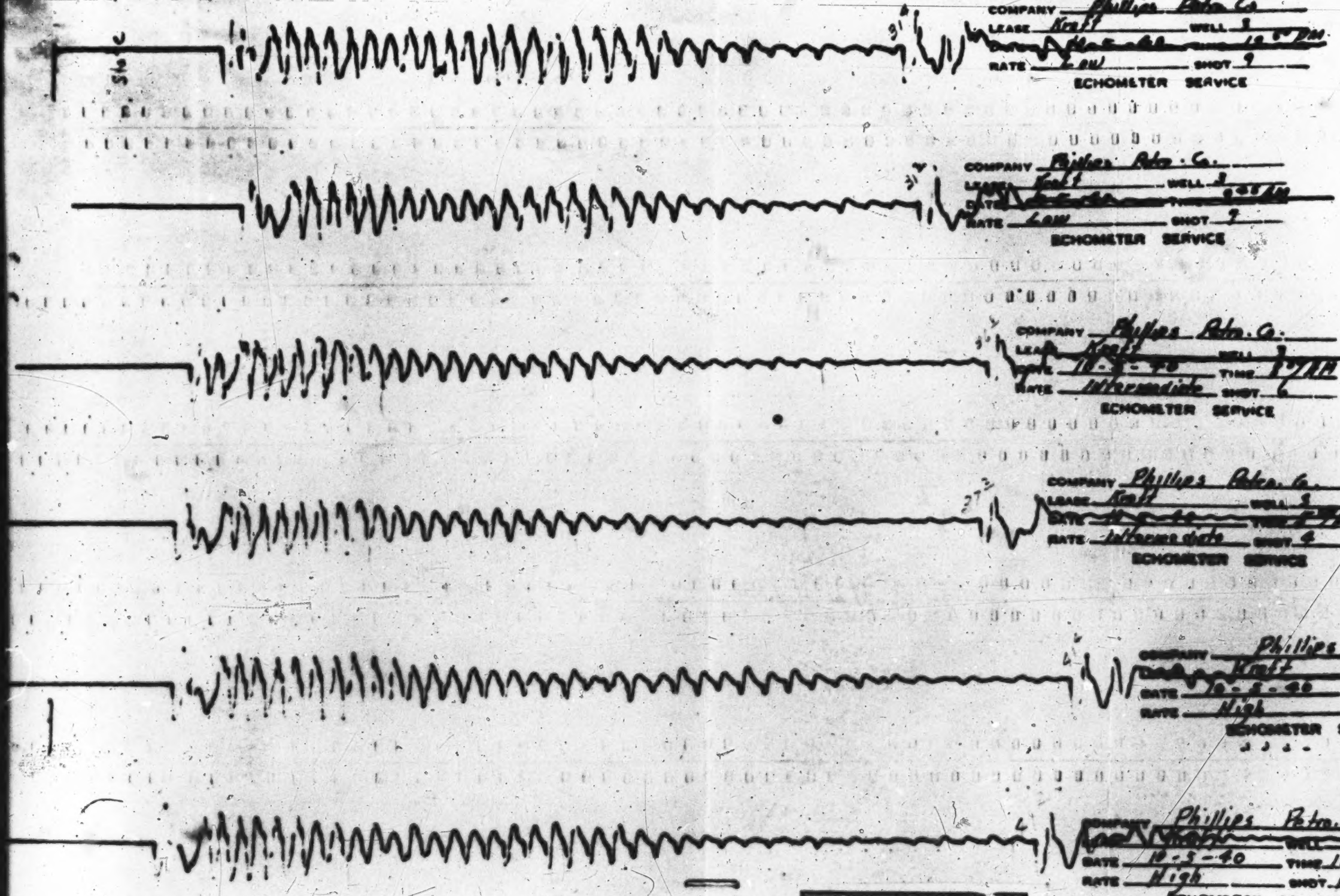
No. 1602 Eq
Baker
vs.
Hubbard
EXHIBIT
No.
Filed OCT. 6 X. 1942. 19.....
EDMUND L. SMITH, Clerk
By
Deputy Clerk

10



No. 1655-PH
Walter
vs.
Halliburton
et al. EXHIBIT
No. 10-B
Filed OCT 6 - 1942 19
EDMUND L. SMITH, Clerk
By
Deputy Clerk

Plo Ex 5



PLAINTIFFS' EXHIBIT 6

No. 1656-PH
Walker
vs.
Halliburton
Plf. EXHIBIT
No. 10-C
Filed OCT 6 - 1942 19
EDMUND L. SMITH, Clerk
By
Deputy Clerk

IN THE DISTRICT COURT OF THE UNITED STATES
SOUTHERN DISTRICT OF CALIFORNIA
CENTRAL DIVISION

CRANFORD P. WALKER: and CRANFORD P. WALKER, D. A. WALKER, ROBERT P. MILLER and MILO C. KETCHUM, doing business as DEPTHOGRAPH COMPANY, Plaintiffs,	
vs.	No. 1655 - H
HALLIBURTON OIL WELL CEMENTING COMPANY, a Delaware Corporation, Defendant.	C I V I L

DEFENDANT'S EXHIBIT NO. 16

accompanying

DEFENDANT'S ANSWERS TO INTERROGATORIES PROPOUNDED BY PLAINTIFFS

No. 1655-PH
Walker
vs.
Halliburton
EXHIBIT
No. 11-A
Filed OCT 6 - 1942 19
EDMUND L. SMITH, Clerk
By
Deputy Clerk

11-A

No. 10513
UNITED STATES CIRCUIT COURT OF APPEALS
FOR THE NINTH CIRCUIT
FILED
AUG - 3 1943
PAUL P. O'BRIEN,
CLERK

Def. Ex. 16

IN THE DISTRICT COURT OF THE UNITED [illegible]
SOUTHERN DISTRICT OF CALIFORNIA
CENTRAL DIVISION

CRAWFORD A. WALKER, [illegible] CRAWFORD P. WALKER, D. A. WALKER, ROBERT J. MILLER and WILLO C. [illegible], doing business as DEPTHOGRAPH COMPANY,

Plaintiffs,

vs.

HALLIBURTON OIL WELL CEMENTING COMPANY, a Delaware Corporation,

Defendant.

No. 1654 - R

CIVIL

DEFENDANT'S EXHIBIT NO. 17

[illegible]

DEFENDANT'S ANSWERS TO INTERROGATORIES PROPOUNDED BY PLAINTIFFS

No. 1654-PH
Walker
vs.
Halliburton
Filed
Rule 33 - Interrogatories
Answers to Interrogatories

11-B

16,518

FILED

AUG - 3 1943

PAUL P. O'BRIEN,
CLERK

NARRATION OF PLAINTIFFS' EXHIBIT NO. 11-C

ECHO-METER FIELD MANUAL

FOREWORD

It is the purpose of this manual to help the Echometer operator. * * * All material in this manual, together with the additional material to be forwarded from time to time, is the sole and exclusive property of the Halliburton Oil Well Cementing Company, and is being distributed for your guidance and use in rendering service to clients of HOWCO. This material is to be considered strictly confidential, and will be made a part of the inventory equipment.

Daniel F. Elam,
Echometer Supervisor.

DFE:gs
July, 1940

WELL EQUIPMENT

The Casinghead Unit

(1) The Casinghead Unit is considered an integral part of the Echometer equipment because it contains the wave-initiation mechanism and a detecting microphone, both essential to proper operation of the Transducer and the Recorder.

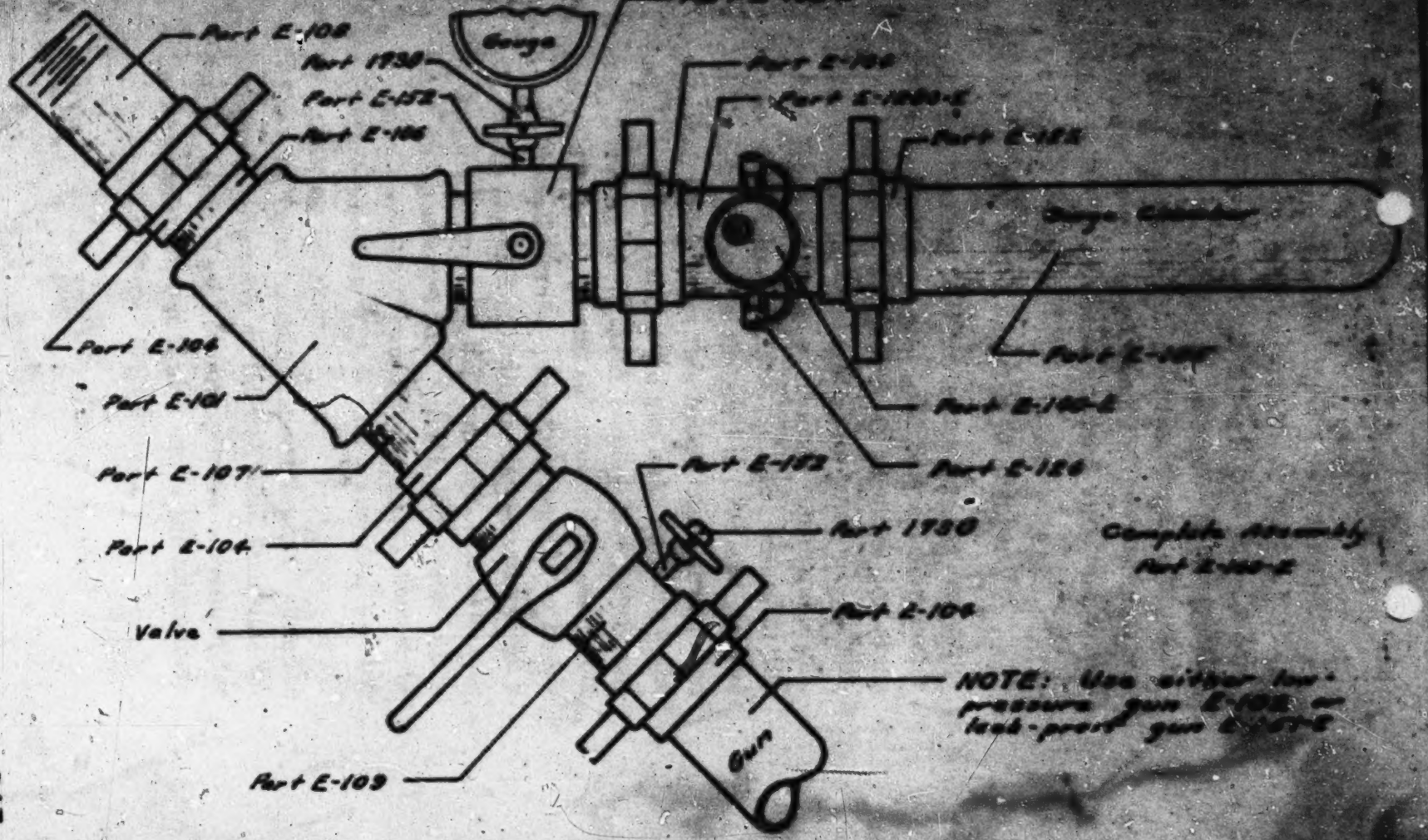
Operation

The Casinghead Unit should be attached immediately upon arriving at a well (See Drawing 7490),

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

and care should be taken to see that all joints are tight and not leaking gas. A leak at any connection, particularly at a point back of the mike, will cause a bad record due to high-frequency noises, which may obscure tubing collar reflections and even the fluid level. Any gas lines leading from the casing should also be shut in, or disturbing acoustical effects may result.

The method of loading and firing the Echometer gun is obvious upon inspection. Make certain, however, when using 10-gauge blanks that the butterfly valve (part E-130-E) which protects the microphone is closed for the shot (handle in line with gauge). A small hole in the disc of this valve passes enough wave energy to record the shot signal and the first few tubing collar reflections, but the valve should be opened (in line with surge chamber) soon After the shot in order to admit the weaker and deeper collar reflections. Whenever the fluid level is high and little sound energy is needed to obtain a record, a .38 calibre blank may be fired by using an adapter bushing in the (2) gun. In this case the butterfly valve may be left open and no damage will result to the mike, because of the smaller explosion.



Revised by RWC Date 5-7-42 Revised by Date	PARTS LIST AND ASSEMBLY ECHOMETER CASINGHEAD UNIT HALLIBURTON OIL WELL CEMENTING CO. - Duncan, Ok.	Drawn by Checked by Date Book No. 2100

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

An electric cable, with 4-pin Jones plugs, makes the necessary connection between the detecting microphone, signal light, and instrument equipment. This plug must be attached to the terminal box (Part E-140E) on the casinghead unit, and to the Transducer cabinet. * * * (3)

The Valve and Gun Mechanism

At the present time there are two general types of Echometer guns in use. The original Winchester salute cannon (Part E-102) is adequate for areas where wells of low casinghead pressure are encountered. However, if the wells make considerable gas, an undesirable leak around the shell occurs at the gun breech until after the shell is fired and its case expanded, which stops this leak. Since production men in general try to avoid gas leaks on their wells, they therefore hesitate to employ any equipment which deliberately creates this undesirable condition. A bad leak also causes premature signals to be recorded and makes it difficult for the operator to set a proper initial gain on his amplifier. To overcome these disadvantages, the special Echometer high-pressure leak-proof gun (Part E-151) should be used, in connection with a plug valve and bleeder. (See drawing 7490).

The plug valve renders it unnecessary to close the permanent gate valve on the well head each time for gun reloading. This not only is more convenient for the well assistant, but it also leaves the microphone

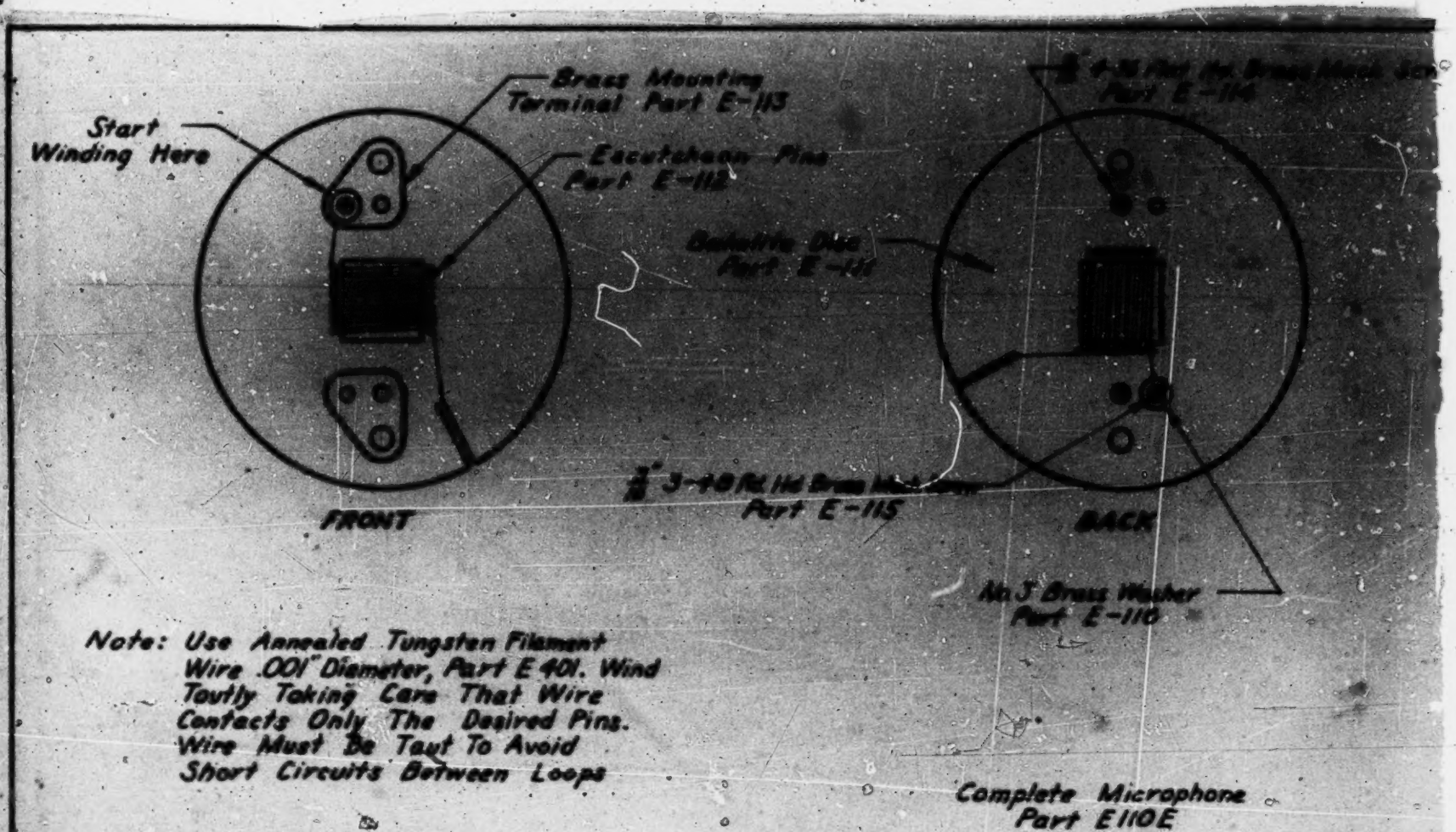
Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

at a constant pressure throughout the series of measurements, thereby eliminating (4) possibilities of damage due to bleeding and re-pressuring the entire Casinghead Unit after each shot. * * *

It can therefore be seen that the use of a plug valve and a leak-proof gun are essential to the smoothness and efficiency of well operations whenever gas is encountered.

The Microphone

The conventional type of microphone does not possess the desired frequency response for Echometer work. After considerable experimentation, a modification of the hot-wire microphone developed by Tucker during the World War has been employed. The system comprises, essentially, an electrically heated thin strip conductor and a means of producing a small blast or movement of gas past it. Our adaptation of the microphone has a frequency characteristic which allows it to successfully pick up frequencies from a fraction of a cycle per second to above 40 cycles per second. This range is sufficient to cover any application to Echometer work. The microphone as it is used is used as a velocity apparatus, actuated primarily by the movement (5) of the gas past it. Other types of detectors (such as that used in Depthograph apparatus) are sensitive only to changes in pressure.



Note: Use Annealed Tungsten Filament Wire .001" Diameter, Part E 401. Wind Toutly Taking Care That Wire Contacts Only The Desired Pins. Wire Must Be Taut To Avoid Short Circuits Between Loops

R. 725.

650	ECHOMETER MICROPHONE WINDING AND PARTS ASSEMBLY	Drawn By O.R.S.
	HALLIBURTON OIL WELL CEMENTING CO., Duncan, Okla.	Date 6-7-40
		No. 7458

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

Construction

The mounting of the microphone is a circular disk, made of Bakelite, in which a hole has been cut from the center (See drawing 7458). In addition to winding pins are the necessary anchor screws to hold the thin wire conductor and two mounting holes for attaching the microphone to the casinghead unit.

"Winding" a microphone is very important, as its electrical characteristics should be fairly constant. (Drawing 7458). Tungsten wire 1-mil (1/1000") in diameter is used. This wire is anchored under the set screw on the front (as the microphone rests in the Casinghead Unit) and is strung back and forth over the pins on the face of the mounting. The last pin over which the wire passes should be beside the diagonal slot. Pass the wire through the slot and continue the winding on the back of the mount, securing the end of the wire with the anchor screw. Approximately 80 cm. of wire constitute the active part of the grid. Proper operation of the equipment cannot be obtained if the grid wire is too long or too short. * * * (6)

Electrical Characteristics

The windings on the microphone have a resistance of about 80 ohms at atmospheric temperature, but when current is passed through the windings their resistance is markedly increased (to about 200 ohms). Herein lies the secret of microphone operation. The reflected waves from the tubing collars, which pass across the windings of the microphone,

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

have a cooling action on the hot wires, changing their resistance and thereby introducing a very small signal to the input of the amplifier. This signal is amplified from a very small current variation to a level high enough to operate the direct-writing Recorder.

The microphone current is furnished from one or more "B" batteries, connected, by a 3-pin Jones plug to the amplifier chassis. A master control on the chassis closes the circuit when switched to "Mike" position. Current values are read directly on a meter mounted on the amplifier panel, and should be about 200 milliamperes at atmospheric conditions. * * * (7)

It has been found that the use of a long surge chamber (Part E-105)—which greatly increases the sensitivity of the microphone—often will produce spurious indications on the record. For this reason, a short chamber (one or two feet in length) is used back of the grid to pick up the tubing collar reflections. * * * Do Not Attempt to Use Any Sort of Acoustical Tuning.

Patents (8)

Specification and Constructional details of the grid-type detectors are given in U. S. Patent No. 1,351,356, issued August 31, 1920 to William S. Tucker. (9)

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

INSTRUMENT EQUIPMENT

* * *

Principle of Operation

There is no mystery about the sound initiation. The firing of the special cartridges simply creates a steep-front wave, which has high frequency components and a superimposed velocity due to the expansion of gas used for creating the wave. Any frequencies coming from the well above 50 cycles are not picked up by the microphone; those below 10 cycles are rejected by the transducer. Therefore, the Echometer faithfully reproduces and records only the frequencies coming from the well over a relatively narrow band. Tubing collars, mid reflections, liner reflections, etc., fall within this band.

Voltage supply for the transducer is a 6-volt storage battery. * * * Power for the recorder motor is furnished by 12-volts, or two storage batteries in series. * * * (10)

Schematic drawings Nos. 7515 and 7531 show the Echometer Transducer and Recorder circuits. * * * (11)

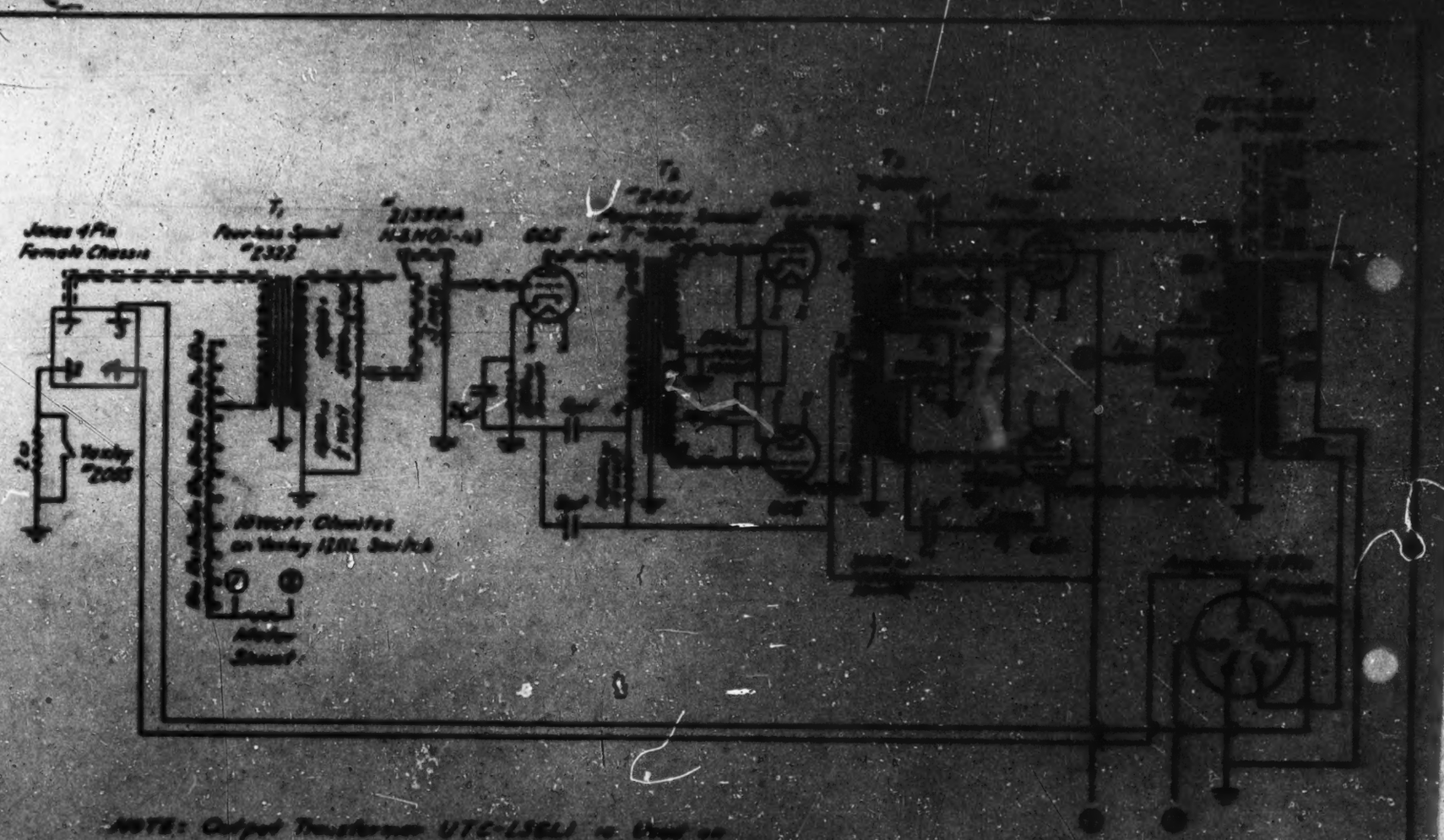
The Transducer

Operation

The transducer is turned on by placing the Master Control at "Fil" position. This causes the filaments of the tubes to heat, and requires about thirty seconds. If the tubes have not sufficiently warmed, when the switch is turned to "Power" for recording, the indicating meter will not read the normal

Narration of Plaintiffs' Exhibit No. 11-C
(Continued,)

operating current of about 90 milliamperes, but will gradually rise to this value as the tubes become warmer. A jeweled indicating reflector is lighted when the transducer switch is in any position besides "Off".



NOTE: Output Transformer UTC-LS6J is Used on Instruments #5 and After. Refer Parts Manual. Additional Winding For Use With Printer Monitor as Separate Indicator Connections.

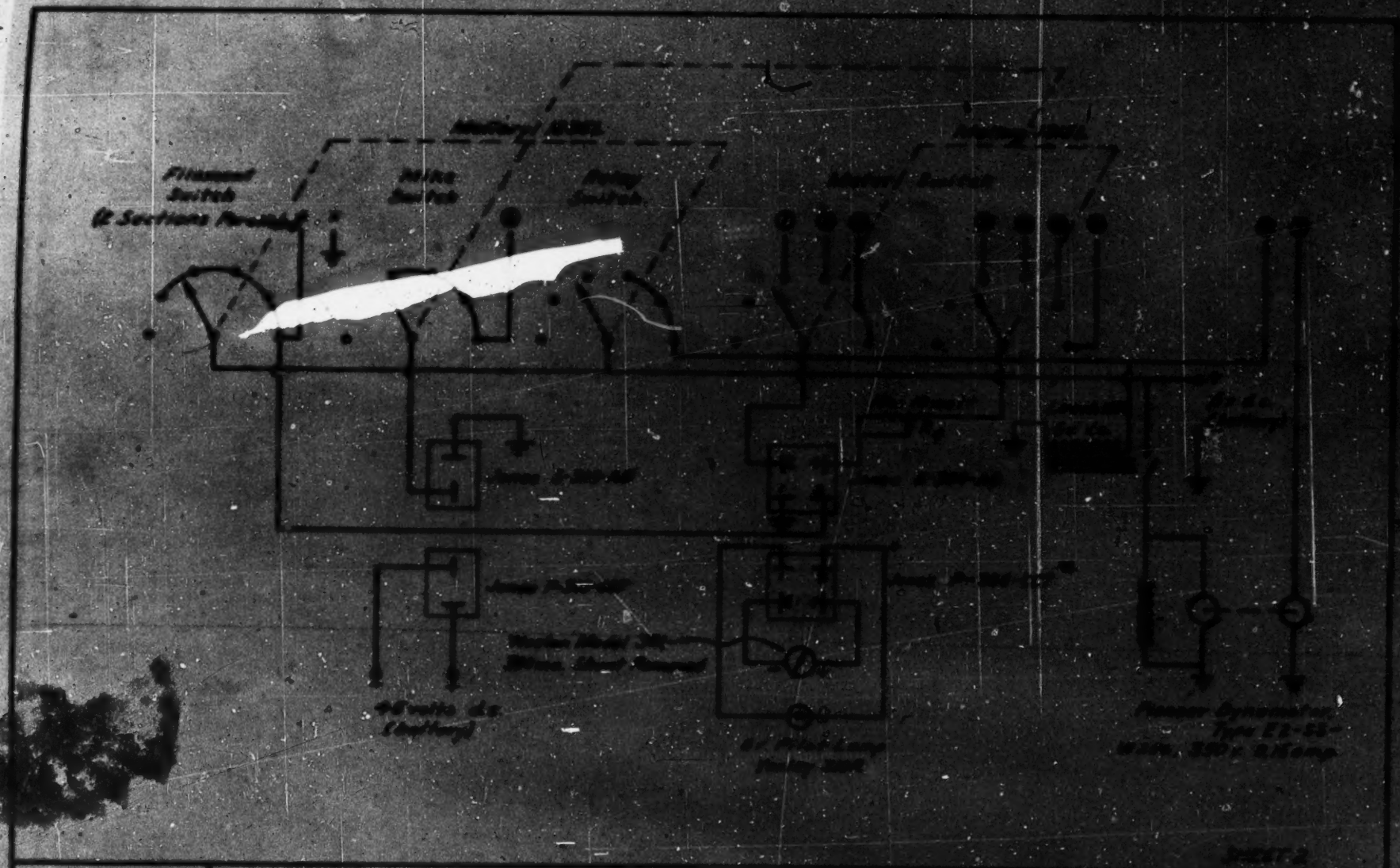
SHEET 1

654

SCHEMATIC OF ECHOMETER AMPLIFIER

HALLIBURTON OIL WELL CEMENTING CO. DUNCAN, OKLA.

731



655

SCHEMATIC OF ECHOMETER AMPLIFIER

HALLIBURTON OIL WELL CEMENTING CO. DUNCAN, OKLA.

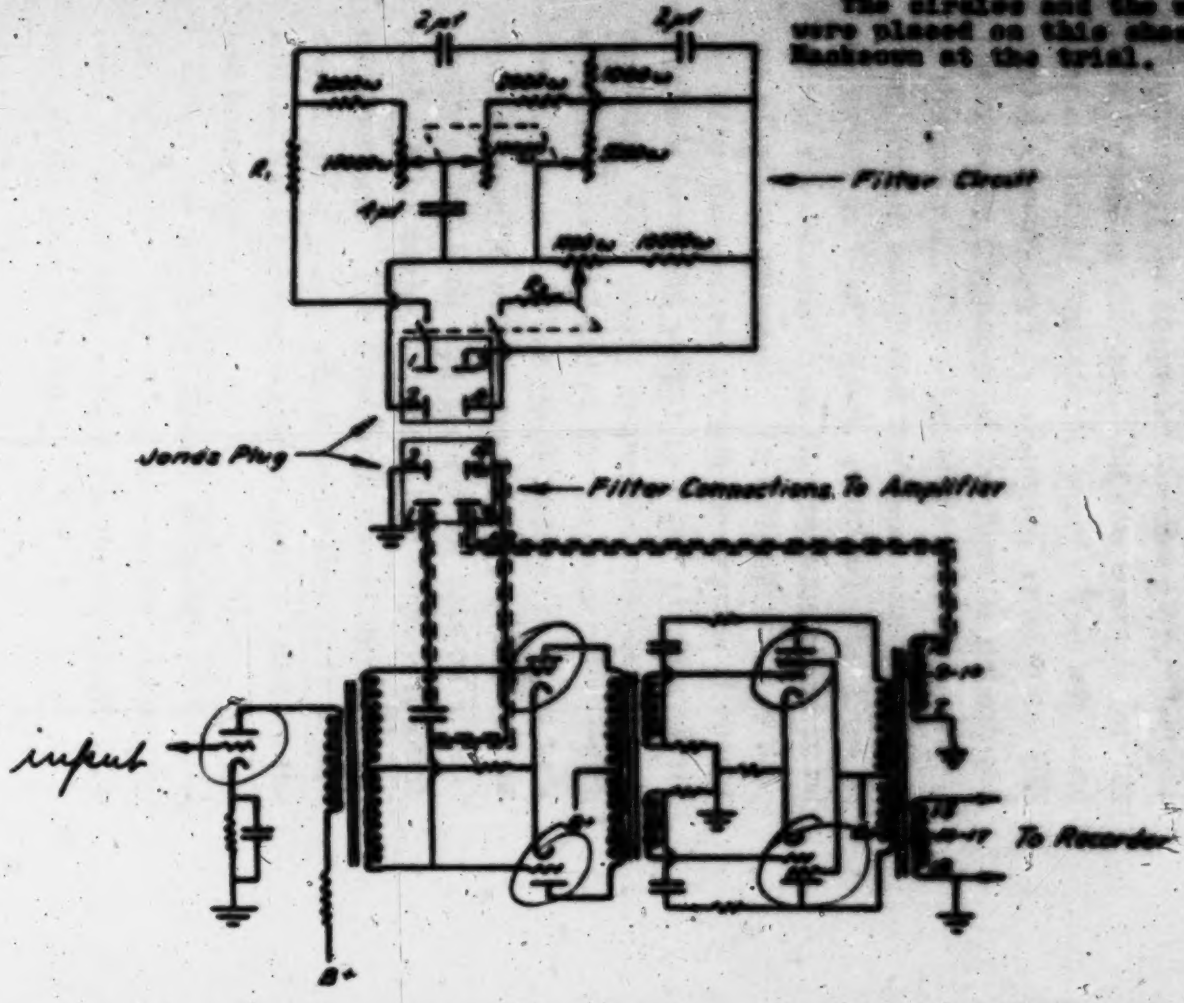
Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

The "Mike" tap is placed between "Fil" and "Power" in order that the operator can observe the electrical character- (12) istics of the microphone immediately before and after each shot. (See Drawings 7531). * * *

When the Master Control is in "Power" position, the output of the transducer is fed into the ink recorder. It is in this position that the instrument operates. "Plate 1" and "Plate 2" are testing taps that should be employed at the beginning of each day's work. When the control knob is turned to "Plate 1" the meter on the panel indicates the plate current in the first output tube (6L6), which should be approximately one-half the total current flowing in both tubes at "Power" position. Similarly, "Plate 2" should read about one-half the total current. * * *

To increase or decrease the magnitude of the reflections (13) recorded, a "Gain" or "Amplitude" control is provided. It is located on the transducer panel, and is calibrated from 0 to 100. Conveniently located is a "Hi-Low" switch in series with the "Gain" control. The "Hi" side with approximately 10 times the amplification of the "Low" side, is in effect extending the scale from 100 to 1000 arbitrary units.

The circles and the word 'input' were placed on this sheet by Mr. Ransom at the trial.



133	SCHEMATIC OF ECHOMETER ELECTRICAL FILTER	Drawn By O.R.S.
	HALLIBURTON OIL WELL CEMENTING CO. DUNCAN, OKLA.	Checked By [illegible]
		Date 6-12-40
		No. 7506

734

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

Operation of Filter

* * * Drawing No. 7506 is a schematic of the circuit.

The electrical filter is designed to filter and selectively amplify the frequency produced by reflections from the tubing collars. The two controls for the filter are on the transducer panel. The left hand control (Frequency) is calibrated from 0 to 100. The response frequency of the filter is determined by this control. The other control (Decrement) is a combination switch and feed back control. When the switch is "Off" (zero position), the filter is entirely disconnected from the transducer and in no way affects its operation. In addition to its switching action this control adjusts the amount of energy fed back from the output to input circuits of the amplifier. This energy causes the amplifier to have a tendency to oscillate at the frequency for which the filter is set. When the decrement is set as near zero as possible without turning the switch off, no energy is fed back and the circuit acts as a filter alone. With higher settings the tendency to oscillate increases. The Feed-back should never be increased to a point where oscillation (14) occurs without some exciting signal to start it (such as the test button).

Before operating the filter it should be calibrated for frequency. The most convenient calibration curve is one of filter setting vs. record length of a cycle of the filter frequency. * * *

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

When using the filter on a well, one record should always be made in the usual manner with the Decrement turned "Off". By measuring as many tubing collars as possible on this record the average joint length on the record is then determined. The collars measured should preferably be in the (15) deeper parts of the well to avoid any abnormal shortening at the start of the record. Then, referring to the calibration curve for the filter, the setting corresponding to this record length of frequency inasmuch as variations in the recorder motor speed will change the apparent frequency of the filter. If there is any doubt about the filter setting, it may be checked by starting oscillations with the test button and comparing the length of the cycles with the tubing collars on the record from the well. The setting should be as close as possible. Otherwise, beats will appear in the record when the filter is used. Also, if there are any very large variations in either joint length or velocity in the well, it may be difficult to avoid getting beats with the filter. Always compare the filtered with the unfiltered records before leaving a well.

When the feed-back control is set at zero the frequency response of the filter should be a little broader. For this reason the Decrement control should be operated at the lowest practical setting. In wells where the collars are very weak increased feed-back will help to bring out the weak collars. Extreme care must be taken never to set the feed-

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

back so high that artificial collars will be produced. If this is done the calculated fluid depth may be in error, if the frequency setting of the filter is not exactly the same as the collar frequency of the well.

When it is difficult to get good collars the feed-back control should be set so that when the transducer volume control (16) is set at the maximum necessary for the well the push button will cause the filter to generate oscillations for not over 10 cycles. The filter will give the transducer an over-all amplification somewhat greater than normal for signals of the frequency for which the filter is set. This amplification increases as the feed-back is increased. The filter will have a tendency to decrease the sharpness of the fluid, tubing catcher, and liner top breaks on the record and in some cases it will be necessary to record these points on one record without the filter and then use the filter to improve the tubing collars on the record. * * *

FIELD OPERATION

Obtaining Records

(19) A suggested operating procedure for general field conditions follows:

1. Supervise the attaching of the Casinghead Unit, and see that all valves, flow lines, etc. on the well are properly prepared. Install a new microphone and connect the mike cable from the Transducer. Close the plug valve (part V-111) and Slowly open the gate valve at the well so as not to

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

place undue strain on the mike or on any accidentally loose connections. Load the gun, and Then Open the Plug Valve. * * * *

2. Turn on the "Fil" of the Transducer and permit the tubes to heat. * * *

3. Rotate master switch to "Mike" (or "Grid") position and check the mike. * * * Set the grid current as previously explained.

4. At the first shot each day, check the plate currents at "Power" "Plate 1" and "Plate 2" positions. (See "Transducer-operation").

5. Return master switch to "Fil" and arbitrarily set "Gain" or "Amplitude" to 50 "Lo", or to some other value chosen after obtaining a small kick of the recorder cylinder by using the test button.

6. Start the recorder motor. * * * (20)

7. Make certain the plug valve in front of the gun is Open to the well; then signal for the shot. Your attendant at the well will fire the gun, close the plug valve, bleed off the gas, and re-load for another record.

8. Be prepared to increase or to decrease the "Gain" as you observe the recording from the shot. From the experience of this first record, better manipulation of the instrument will result on subsequent shots. Always, however, start with a low gain and increase the control as the deeper well reflections become naturally weaker. The recorded signals should be approximately of uniform magnitude along the entire length of the record. * * * *

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

9. If disturbing high-frequencies are present on the record, or if the tubing collars are not clear, the filter may be used to clean up the record. Obtain a proper filter setting from the calibration curve and compare the filtered and unfiltered records before leaving the well. (See section on "Operation of Filter".) * * * * (21)

Computation of Records

* * * *

By Collar Count

In the normal use of Echometer equipment, the gun will be fired into the casing annulus. Therefore, each joint of casing and tubing exposed above fluid will tend to slightly obstruct the sound wave, and will cause small impingements to reflect back to the microphone at the casinghead. Since the magnitude of these reflected waves is depending upon the per cent change in (22) cross-sectional area of the annulus, it can be seen that reflections from casing joints are inferior in magnitude, or signal strength, to those caused by tubing couplings and therefore will not be discernible. Thus, when the instrument is so adjusted as to record "tubing collars", either a tubing tally or an average length of joint for the well can be used for computation purposes. However, the accuracy of the computation from these collars is limited by the reliability of the tubing tally, or average joint length submitted by the client. * * *

Narration of Plaintiffs' Exhibit No. 11-C (Continued.)

Under average conditions, each exposed joint of tubing will be indicated on the Echo record, and the depth to fluid can be interpolated to the nearest 0.1 of a joint. Long subs at the top are usually indicated, and a tubing string of mixed joints will normally show the relative joint lengths and sizes.

By Graphic Extrapolation

Whenever tubing collars cannot be recorded all the way to the fluid, a close approximation of the fluid depth can be had by extrapolating the deeper collars on the record. Perhaps the best manner of doing this is to plot the "measured length of record" (Time) against "well depth in tubing collars" (Distance). The resulting graph will show velocity of the sound wave in this particular well. A line through the deeper collars can then be extrapolated to a point representing the measured length to fluid, and will show the fluid depth in terms of tubing collars. (23)

Due to possible "abnormal" velocity changes near the top of the well (as explained under "Calibration Procedure") only the deepest recorded collars should be used for extrapolation purposes. Top collars may be recorded shorter, due to a higher wave velocity, and thereby if used will give a fluid level that is too deep.

By Well Velocity

Whenever the fluid level is below some recognizable well point, which has a known depth, (a tubing

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

catcher, liner top, or gas-lift flow valve), no appreciable error is involved if depths are computed by proportional measurement of record lengths, as:

$$\frac{\text{Length of record to catcher}}{\text{Length of record to fluid}} = \frac{\text{Depth in feet to catcher}}{\text{Depth in feet to fluid}}$$

This is, in effect, computing the fluid depth by extrapolating an assumed constant well velocity. The cumulative error is minimized because of the small distance which is extrapolated. * * *

(35) FIELD PROCEDURE

Subsurface Pressures

The subsurface pressure gauge graphically records the total maximum pressure at any desired datum, but in Echometer work the component parts of this total pressure are measured and the sum is computed mathematically, as all the factors involved are technically subject to measurement.

The bottom hole pressure is the sum of the casinghead pressure (P_{ch}), the weight of the gas column (P_g), and the weight of the fluid column. The weight of the gas column can be determined if its length, specific gravity, average temperature, deviation from Boyle's Law, surface pressure, etc. are known. The weight of the fluid is equal to its height (h) times the average density (d). Mathematically, the bottom hole pressure may be expressed:

$$P_{bh} = P_{ch} + P_g + hg \qquad (1).$$

The pressure on the well casinghead can be gauged

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

at the time of the shot initiation. The Echometer record obtained is itself a measure of the length of the gas column. The specific gravity of the casing gas is easily and quickly determined with a postable measuring apparatus. (In ordinary field operation, the effects of temperature, deviation, etc. are of minor importance.) By subtracting the depth to fluid from the depth to the desired pressure datum, the height of the fluid column exerting pressure will be obtained. Substitution of the observed and calculated (36) values can then be made in equation (1).

Specific Gravity of Gas

The specific gravity of the casing gas can best be determined in the field by use of a Schilling bottle, following instructions of the manufacturer. * * * * (37)

Use of Formula or Gas Charts Based Thereon

The basic equation for obtaining the weight of a column of gas under pressure is known as the Dice formula:

$$\text{Log}_{10} P = \frac{SH}{122.82\ (t + 460} + \text{Log}_{10} p \qquad (38)$$

where P is the total absolute pressure at the base of a gas column and p is the absolute pressure at the top of the column. S is the specific gravity of the the gas and H is the length of the column. The average Fahrenheit temperature of the gas is designated by t.

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

To render this formula more usable in the field, it has been solved and the results plotted as gauge pressures on four charts (not in printed record).

* * * *

Fluid Density and Fluid Pressure Gradient

In cases where a low gas/oil ratio exists, or where the oil produced is extremely heavy, little error will result if a uniform fluid gradient is assumed in the well and the effects of gas are neglected. On simple draw-down capacity tests, "feet of (39) fluid" may be plotted directly against "gross rate of production" to indicate the well's potential. Likewise, "feet of fluid" multiplied by the gradient gives the subsurface datum pressure.

In computing shut-in subsurface pressures, the average fluid density is generally known from previous experience in a particular field and can be correctly assumed. If necessary, however, measurements can be plotted for the changes in equilibrium fluid height at two or more different casinghead pressures and an extended line drawn through these points—thereby determining the casing pressure necessary to depress the fluid to any desired depth. When the fluid has been thus theoretically removed above the datum, the bottom hole pressure must be in equilibrium with the total pressure of the gas above. Therefore, the weight of the theoretical gas column at desired depth plus the casinghead pressure as determined by extrapolation to that depth

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

will equal the datum pressure. This same procedure may be employed to determine producing subsurface pressures by keeping the production rate constant during a series of back-pressure measurements.

In wells producing gas, the fluid gradient in the annulus of the well depends not only upon the producing conditions but also on the effective area of the annulus. For given producing conditions, the fluid gradient in the annulus is assumed constant from the top of the fluid to the perforation, provided there is no change in casing size. It has been found that the gradient varies from about 0.05 to 0.5 pounds per square inch pressure per foot of depth below the fluid level, depending upon the gas/oil ration. * * * (40)

Normally, the Echometer operator will be responsible for the field work only, and will fill out merely the columns pertaining to such, as: Lease, well number, time and date, joints to fluid, casing-head pressure, production, and remarks. Such data as the average joint length, feet to fluid, datum elevations, pressures, etc., should be furnished or completed by the client. However, it is always a good policy to supervise the averaging of tubing tallys, method of pressure computations, etc. to be sure the client is handling the data properly and without difficulty. * * *

Determination of Subsurface Pressure

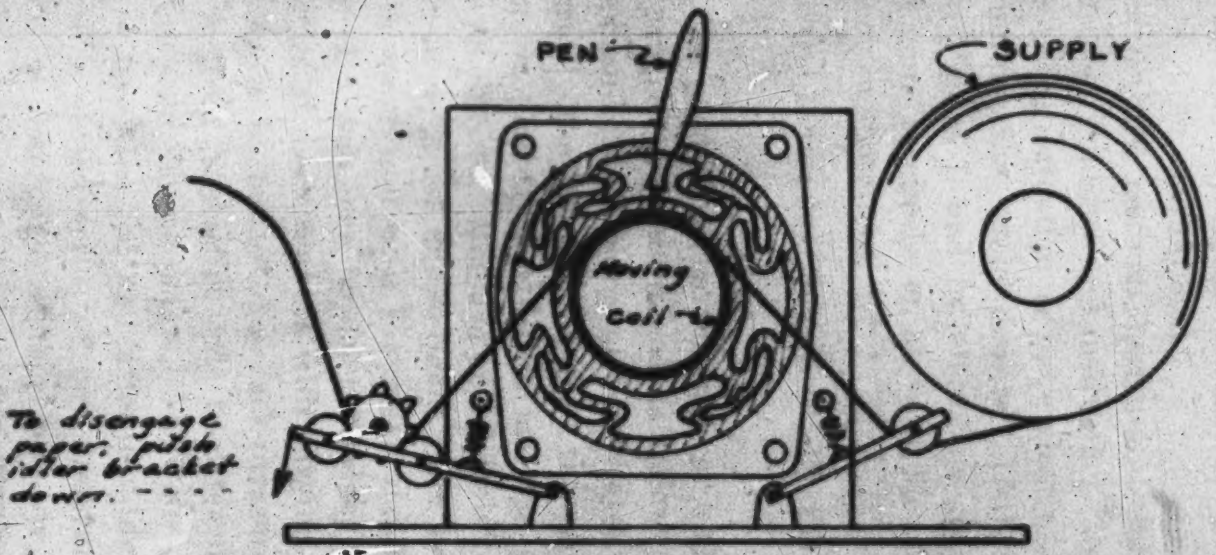
The original bottom-hole pressure, and its rate of decline, are of considerable importance to the pet-

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

roleum engineer. These data may be obtained by direct measurement with a subsurface pressure gauge or they may be calculated from the known relationships of fluid level, casing-head pressure, and rate of production.

A plot of fluid-level data with h as ordinate and total gas pressure on the fluid as abscissa is a straight line, provided the production rate is held constant and the density does not vary with depth. Hence, the pressure at the reservoir dept., P_1, may be obtained by extrapolation. This method of computation illustrated in Figure 1, is patented by a competitor, and should not be used.

A more rapid method which is free of any patent litigation and which involves the determination only once of the weight of the gas column is illustrated in Figure 2. The production rate is maintained constant and two or more measurements are made of fluid levels versus casinghead pressure. Extrapolation of the data to the depth of the mean producing horizon gives the theoretical casinghead pressure necessary to force the fluid-level down to the producing horizon. The total pressure at this depth may be obtained by adding the weight of the gas column at that depth to the extrapolated casinghead pressure. Referring to the figure, the extrapolated casinghead pressure was found to be 258 pounds, while the calculated weight of the gas column was 47 pounds; giving a total formation pressure of 305 pounds.



DETAIL OF PAPER TRAVEL

PLATE III.

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

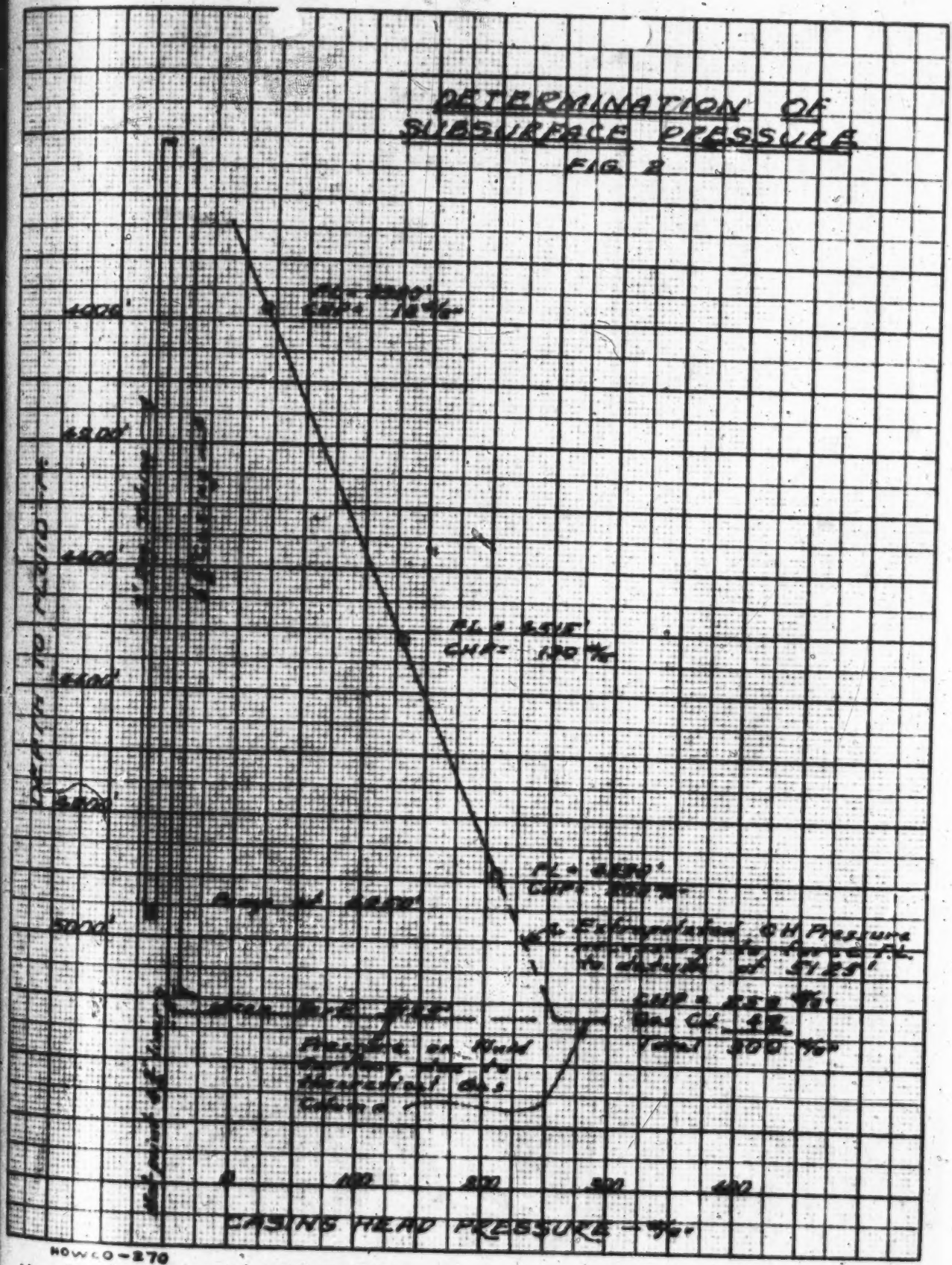
The competitive methods herein illustrated are shown for your guidance and instruction. However, until the patent situation is more clearly defined, do not imitate the "fluid density" (50) method shown in Figure 1, and by all means do not allow your name to appear on any graphical density or gradient computations. * * *

Productivity Determinations in Wells Producing Gas

(58) The producing characteristic of wells making gas can best be determined as follows:

The bottom-hole pressure, at some given datum point—usually the average depth of the producing formation, is plotted as ordinate and the production rate as abscissa. Methods of determining total pressures at a given datum point have been described in connection with Figures 1 and 2. Productivity of a well may be determined by making such a series of measurements with varying casing-head pressures by means of a back-pressure regulator at a given production rate to determine one of the pressure datum points. The rate of production is now changed and after equilibrium is established a second series of measurements (58) are made to determine another pressure datum point. Two or more of such points are then plotted, and the pressure curve extra-polated to zero pressure (where no back-pressure will be exerted against the producing formation) to determine the theoretical maximum production rate for the well. * * * *

671

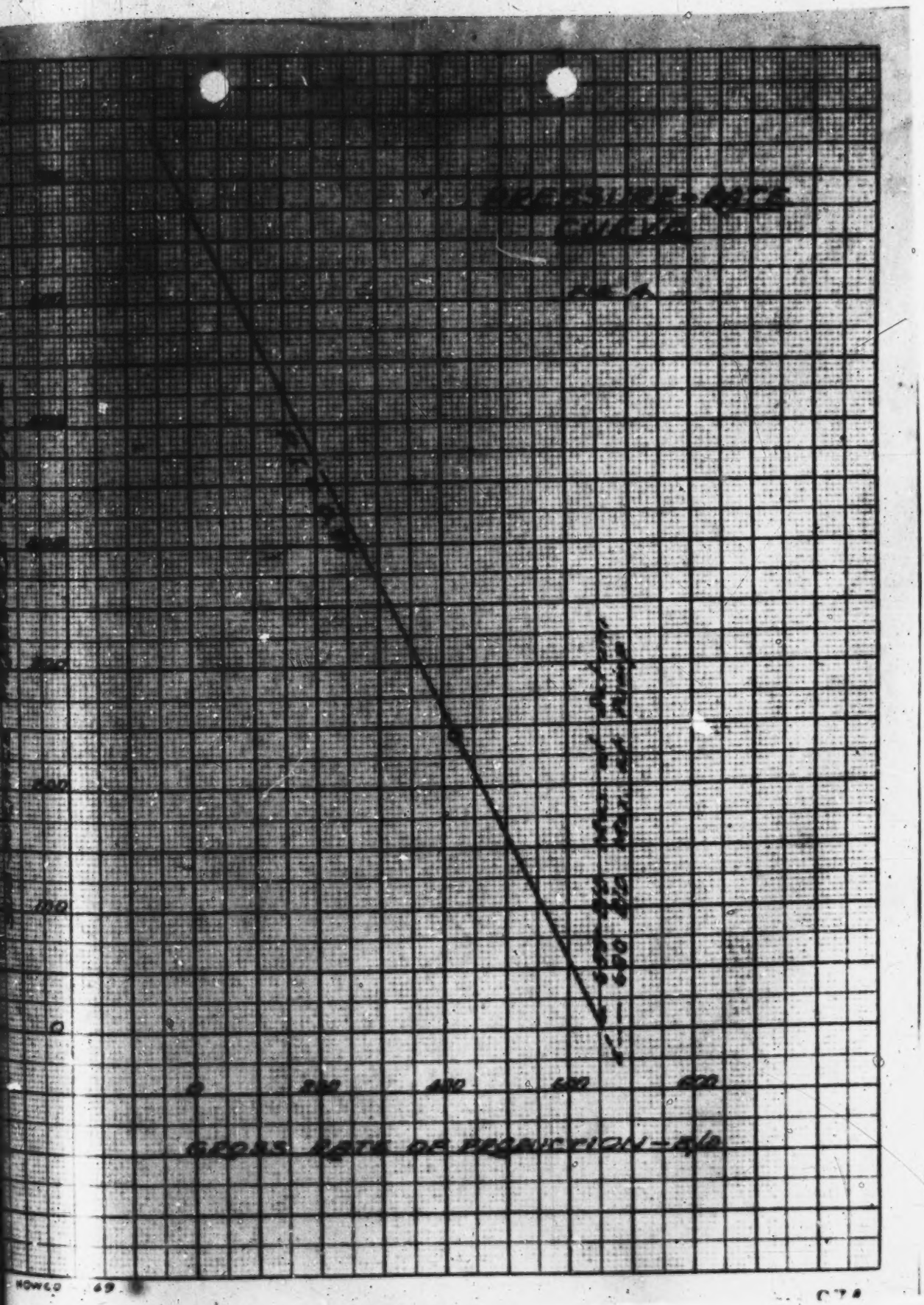

DETERMINATION OF
SUBSURFACE PRESSURE
FIG. 2
4000'
4200'
4400'
4600'
5000'
CASING HEAD PRESSURE — #/sq.
100
200
300
400

HOWCO-270

Narration of Plaintiffs' Exhibit No. 11-C (Continued.)

The Productivity Index

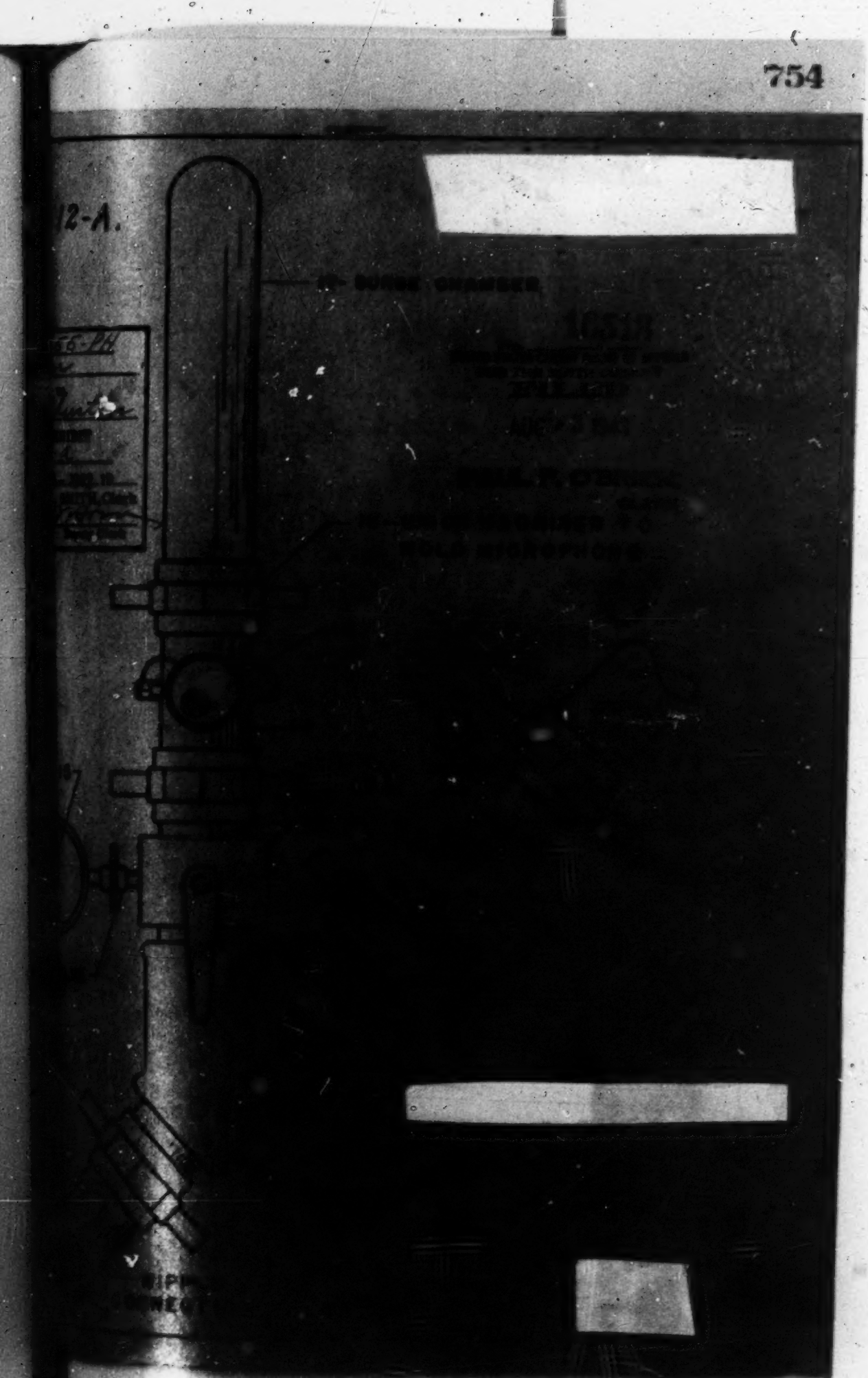
The productivity index is determined from the slope of the pressure-rate curve, (See Figure 4) and is defined as "the barrels per day of gross liquid produced per pound per square inch pressure drop at a specified subsurface datum."


GROSS RATE OF PRODUCTION - B/D

Narration of Plaintiffs' Exhibit No. 11-C
(Continued.)

Any condition tending to change the productive capacity (59) of the well is indicated by a change in the productivity index or slope of the curve. A decreasing productivity will be obtain when the gross production per pound drop in bottom-hole pressure decreases. This condition may be caused by increasing water, a decrease in effective permeability of the oil formation adjacent the well, or by drainage interference from offset wells. In some cases an increased productivity factor may be obtained, especially if the well is cleaning out or channeling. Periodic measurements of this type are a vital necessity in keeping a close check on a well's performance. The decline of a well's potential and its proper pumping conditions can be intelligently followed, and in many cases controlled, by the use of bottom-hole pressure or fluid-level data.

[Endorsed]: Filed June 1, 1943.


12-A.

vs.

EXHIBIT

K

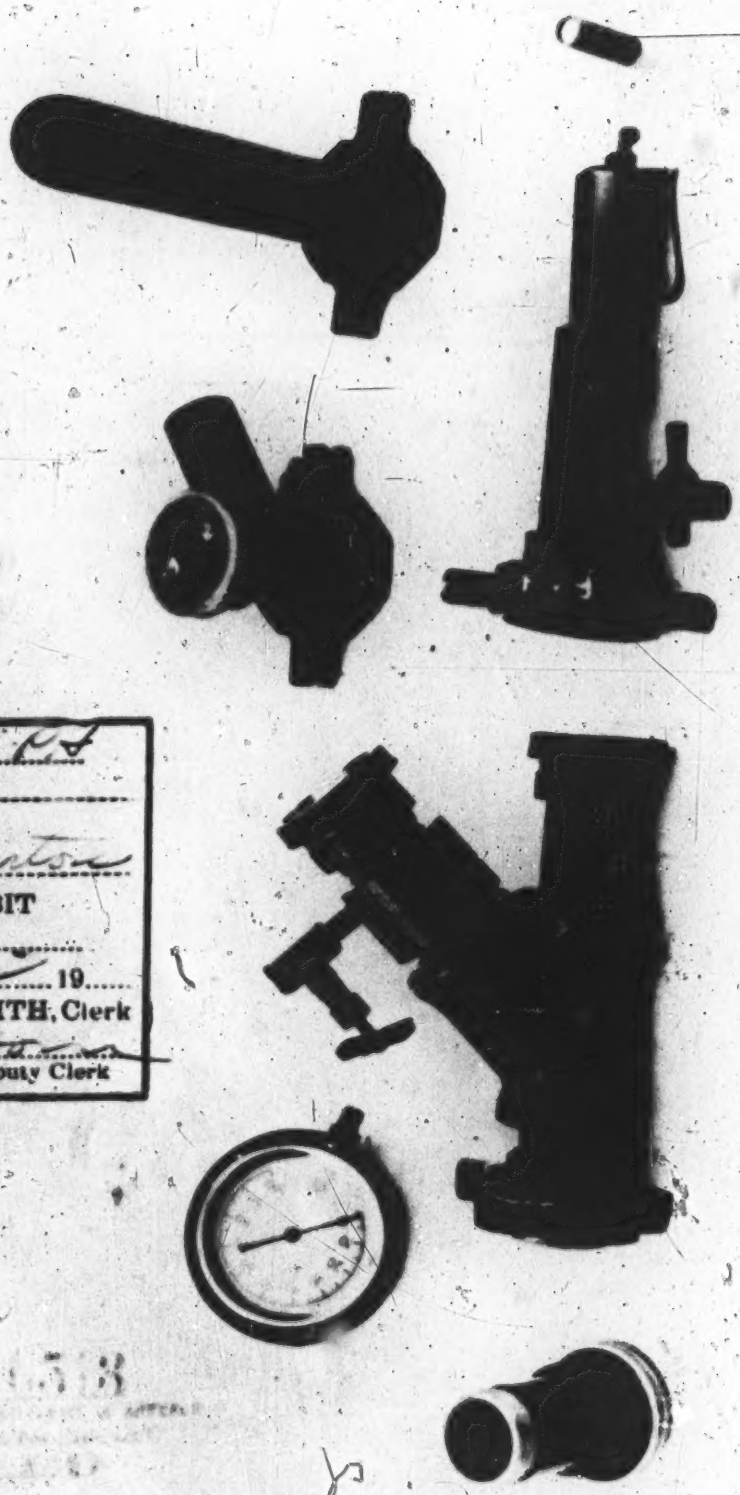
19

D L. SMITH, Clerk

Deputy Clerk

EX. 12-B.

R. 755.



No. 12,558 CA
Wilkes
vs.
Halliburton
EXHIBIT
No. 2
Filed Sept 1 19....
EDMUND L. SMITH, Clerk
By J. Williams
Deputy Clerk

Notary Public

PAUL P. O'BRIEN

DEFENDANT'S EXHIBIT NO. 22.

Edward Gene Spain
Notary Public

No. [illegible]

vs.

EXHIBIT
No. 22-E

Filed [illegible] 19[illegible]
EDMUND L. SMITH, Clerk
By [illegible]
Deputy Clerk

FREQUENCY - Dial Divisions
AVERAGE LENGTH PER CYCLE - MM

PLAINTIFFS' EXHIBIT No. 13

District Court of the United States, Southern District of California, Central Division

Civil

No. 1655-PH

CRANFORD P. WALKER; and CRANFORD P. WALKER, D. A. WALKER, ROBERT P. MILLER and MILO C. KETCHUM, doing business as DEPTHOGRAPH COMPANY, a co-partnership,

Plaintiffs,

v.

HALLIBURTON OIL WELL CEMENTING COMPANY, a Delaware corporation,

Defendant.

STIPULATION AS TO CERTAIN FACTS

Plaintiffs and defendant herein, by their respective counsel, hereby agree and stipulate for the purposes of this trial, that the following facts are true:

That United States Letters Patent No. 2,209,944, No. 2,156,519 and Reissue No. 21,383 were issued by the United States Patent Office to the plaintiff Cranford P. Walker and that plaintiff Cranford P. Walker is the owner of the entire legal title to each of them.

That plaintiff Depthograph Company is a co-partnership comprised of Cranford P. Walker, Dorothy

A. Walker, Robert P. Miller and Milo C. Ketchum and is the sole and exclusive licensee under each of said Letters Patent.

That plaintiffs reside within the County of Los Angeles, State of California, and within the Southern District of California, Central Division.

That plaintiff Depthograph Company is operating a business, substantially the sole activity of which is the furnishing of a service for oil well operators consisting of:

(1) measuring the location of fluid levels and other obstructions and apparatus in oil wells;

(2) the measurement and computing of pressures existing at various points in the liquid column in an oil well from the surface of the column to the bottom of the well bore, known to the trade as "sub-surface pressures";

(3) the measuring and computing of the density of the liquid column, known in the trade as "fluid density determinations and fluid gradients"; and

(4) the determination of the maximum production capacities of which the wells are capable (known in the industry as "production capacity determinations", "well potentials" or "the productivity index of a well");

and that substantially the entire income of plaintiff Depthograph Company is derived from the sale of this service.

The defendant is engaged in many and various

activities in the oil industry and while defendant has made, leased and used apparatus for measuring the location of obstructions in wells and has practiced the method of:

(1) measuring location of fluid levels and other obstructions and apparatus in oil wells;

(2) the measuring and computing of pressure existing at any point in the liquid column of an oil well from the surface of the column to the bottom of the well bore; and

(3) the determination of the maximum production capacities of which wells are capable;

and is continuing to do so, defendant derives the major portion of its income from activities and services other than those complained of in this case.

Certain Facts Relating to the Prosecution of Applications Resulting in Patent 2,209,944

That Walker application Serial No. 270,865 (Defendant's Exhibit D-1) was filed April 29, 1939 and was a division of Walker application Serial No. 162,699 (Defendant's Exhibit D-12) which was filed on September 7, 1937, and that application Serial No. 270,865 is entitled to relate back to and have the effective filing date of September 7, 1937.

That on August 23, 1939 Harold W. Mattingly, Walker's Los Angeles attorney, wrote his Washington associate Raymond Jones requesting Jones to interview the Examiner with regard to said application Serial No. 270,865, said letter containing the following statement:

"I am particularly anxious to receive the notice of allowance and to pay the final fee in this case at the earliest possible moment and I would appreciate your finding out from Examiner Justice in Division 5 how soon I may expect a formal notice of allowance, and if there is anything we can do to speed this up, I will be glad to do so."

That the Patent Office mailed the formal notice of allowance of this application from Washington on September 14, 1939 and on Septembr 15, 1939 Raymond Jones mailed to Mattingly the letter reading as follows:

"Last Wednesday, I had the Assignment Division make special its check on th title of this case.

"The notice of allowance was mailed on September 14 and I paid the final fee that day—Thursday, an issue day.

"You may remit this $30.00 as a separate item."

That this final fee was paid by Raymond Jones before Mattingly received the information that the application had been formally allowed.

That it had never been the practice of Raymond Jones to pay a final fee in any application for which he acted as associate for Mattingly unless Mattingly gave Jones specific instructions for Jones to pay such fee. It was not the intention of Mattingly by the letter of August 23, 1939 to Raymond Jones that Jones should pay this fee but only

that Jones expedite the issuance of the formal notice of allowance and Jones interpreted the letter as instructions for him to pay the final fee, contrary to the intentions of Mattingly.

That the first notification received by Mattingly that the notice of allowance had been entered in this case was received by Mattingly after Jones had paid the fee.

That on September 18, 1939 Mattingly wired Jones as follows:

> "Conditions Suddenly Changed Can You Withdraw Final Fee Walker Case"

That on September 20, 1939 Jones mailed a letter to Mattingly as follows:

> "In reply to your wire sent September 18, this Walker case had the number applied to the drawing last week-end and the file was sent to the printer on Monday. Regardless of these facts, no final fee can be withdrawn after the case is given a patent number.
>
> "Our only remedy, if necessary, is to abandon and re-file. If this is done, the Office should be advised as soon as possible as we did in the parent case.
>
> "I assumed from your letter of August 23 that speed was essential to secure early issue, hence paid the final fee with this in view."

That on September 22, 1939 Mattingly sent to Jones a letter reading as follows:

> "I am enclosing herewith the original of a continuing application which I have prepared

to take the place of the Walker application Serial No. 270,865, together with a statement of abandonment of that application.

"Will you please see that these are filed in the correct order so that the Walker application Serial No. 270,865 will not issue as a patent.

"I hope we won't have to do this again."

That the application referred to in said letter filed to take the place of application Serial No. 270,865 was filed in the Patent Office by Jones on September 25, 1939 and was given Serial No. 296,781, which application Serial No. 296,781 matured into patent No. 2,209,944, one of the patents here in suit.

That the two applications Serial Nos. 270,865 and 296,781 were directed to the same invention. The specification and drawings of application Serial No. 296,781 were the same as the specification and drawings of application Serial No. 270,865 with the exception of the insertion on Page 1 of the statement beginning in Line 11 as follows:

"and a continuation of my application Serial No. 270,865, filed April 29, 1939";

and on Page 2, Line 17, the word "fluid" was changed to read "liquid".

That the wording of Claims 2 and 3 of application Serial No. 270,865 was modified in the correspondingly numbered claims in application Serial No. 296,781 as follows:

Serial No. 270,865:

2. The method of determining the unknown location of an obstruction in a well having a string of tubing therein, which consists in creating an acoustical impulse in the annular space between the tubing and the well casing to produce echoes from portions of the tubing string distinguishable from each other and from the echo from the unknown obstruction, observing the lapse of time between the creation of the impulse and arrival at a pre-determined point of the echoes from successive portions of the tubing string to thereby determine the velocity of the pressure wave through the particular well under measurement, and measuring the lapse of time between the creation of the pressure impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

3. The method of determining the unknown location of an obstruction in a well having a string of tubing therein, which consists in creating an acoustical impulse in the annular space between the tubing and the well casing of such magnitude as compared with the depth of the well and the resistance to pressure wave transmission therethrough as will produce echoes from portions of the tubing string distinguishable from each other and from the echo from the unknown obstruction, observing the lapse of time between the creation of the impulse and arrival at a predetermined point of the echoes from successive portions of the tubing

string to thereby determine the velocity of the pressure wave through the particular well under measurement, and measuring the lapse of time between the creation of the pressure impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

Serial No. 296,781:

2. The method of determining the unknown location of an obstruction in a well having a string of tubing therein, which consists in creating an acoustical impulse in the annular space between the tubing and the well casing to produce echoes from portions of the tubing string distinguishable from each other and from the echo from the unknown obstruction, observing the lapse of time between the arrival at a predetermined point of the echoes from successive portions of the tubing string to thereby determine the velocity of the pressure wave through the particular well under measurement, and measuring the lapse of time between the creation of the pressure impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

3. The method of determining the unknown location of an obstruction in a well having a string of tubing therein, which consists in creating an acoustical impulse in the annular space between the tubing and the well casing of such magnitude as compared with the depth of the well and the resistance to pressure wave transmission therethrough as will produce echoes from portions of the tubing

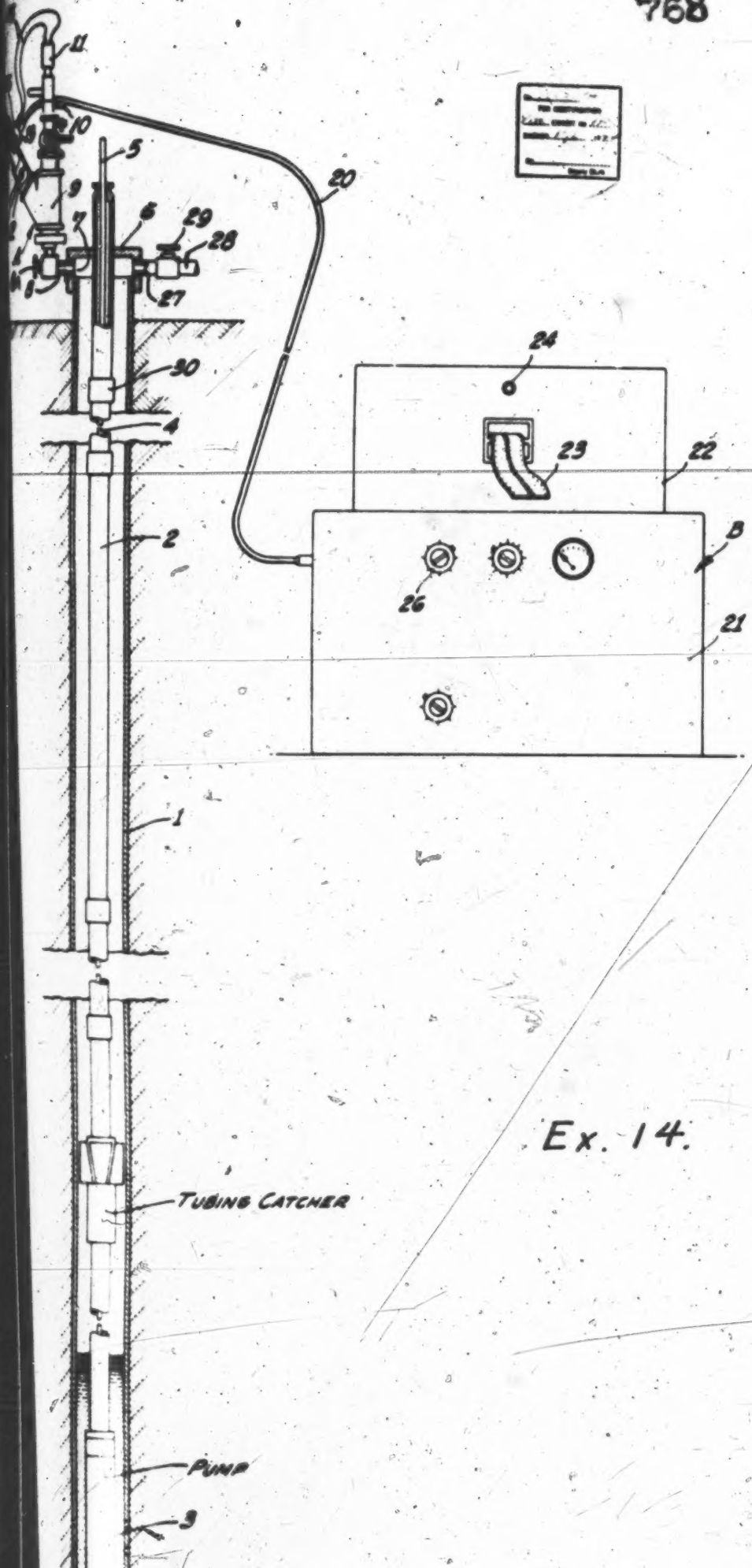
string distinguishable from each other and from the echo from the unknown obstruction, observing the lapse of time between the arrival at a predetermined point of the echoes from successive portions of the tubing string to thereby determine the velocity of the pressure wave through the particular well under measurement, and measuring the lapse of time between the creation of the pressure impulse and the arrival at said predetermined point of the echo from the unknown obstruction.

That Claims numbered 1, 4, 5, 6 and 7 of each of said applications are identical.

HAROLD W. MATTINGLY,
ROBERT W. FULWIDER,
Attorneys for the Plaintiffs.
FRANK L. A. GRAHAM,
EARL BABCOCK,
Attorneys for the Defendant.

Los Angeles, California, October 3, 1942.

[Endorsed]: Filed Oct. 6, 1942.

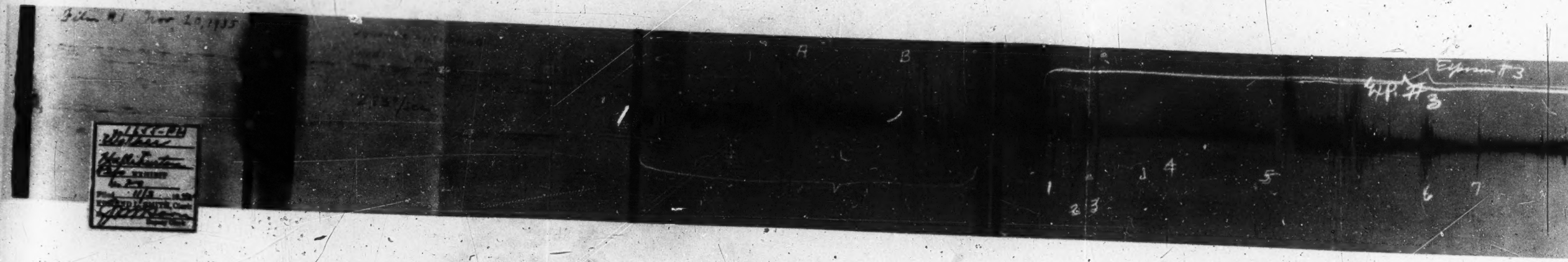

11
10
5
9
7
6
29
28
27
20
24
30
4
23
22
2
B
26
21
1
TUBING CATCHER
PUMP
3

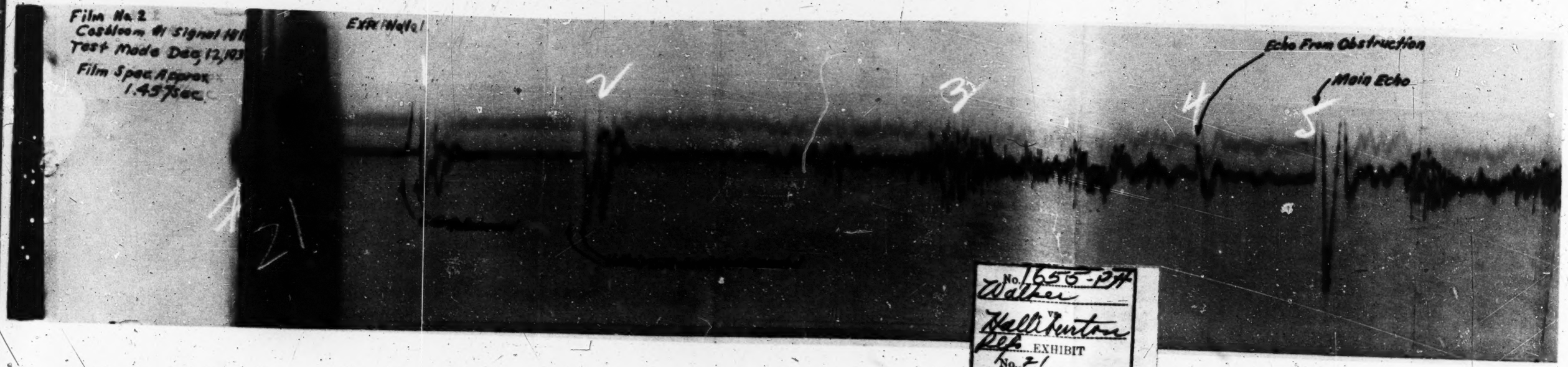
Ex. 14.

PLAINTIFFS' EXHIBIT No. 18

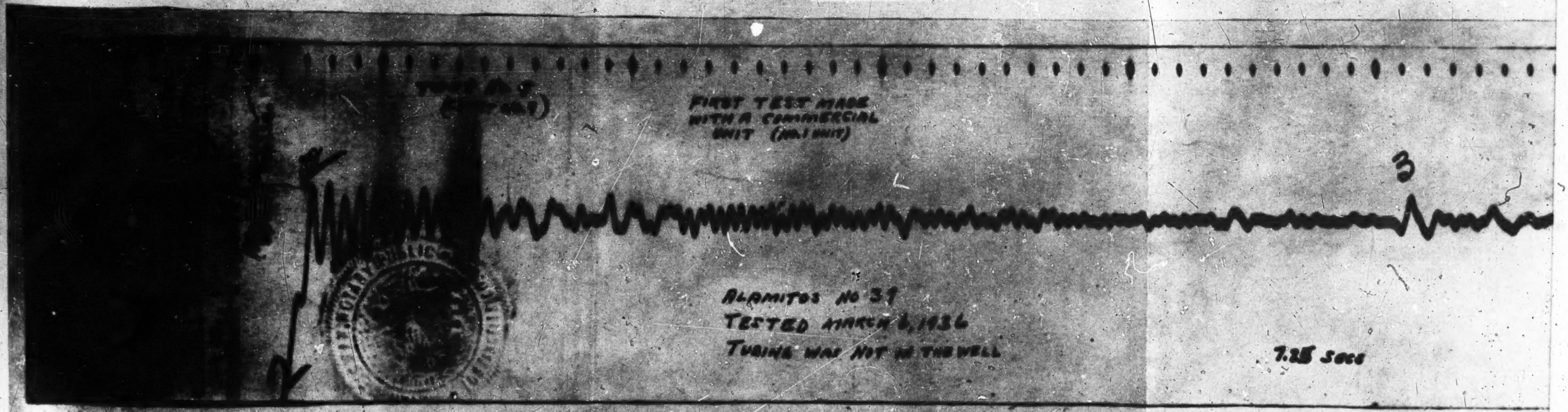
[Printer's Note: Plaintiffs' Exhibit No. 18 is reproduced following Defendant's Exhibit O-9 in this Book of Exhibits.]

[redacted]


Film #1 June 20, 1935
A
B
Eyam #3
Eyam #3
1
2
3
4
5
6
7


Film No. 2
Test Mode Dec 12, 193
Film Spec Approx
1.457sec
Echo From Obstruction
Main Echo
No. 1655-PH
Walker
vs.
Halliburton
Pet.
EXHIBIT
No. 21
Filed 11/3 19 47
EDMUND L. SMITH, Clerk
By
Deputy Clerk

BORE
MID
FIRE

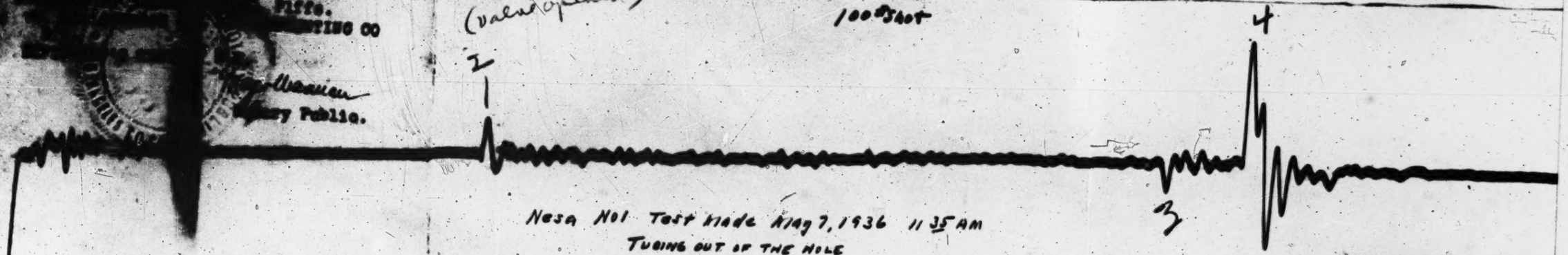

FIRST TEST MADE
WITH A COMMERCIAL
UNIT (NO. 1 UNIT)
3
ALAMITOS No 31
TESTED MARCH 6, 1936
TUBING WAS NOT IN THE WELL
7.25 SECS

1656-H.
Fifth.
TING CO

Notary Public.

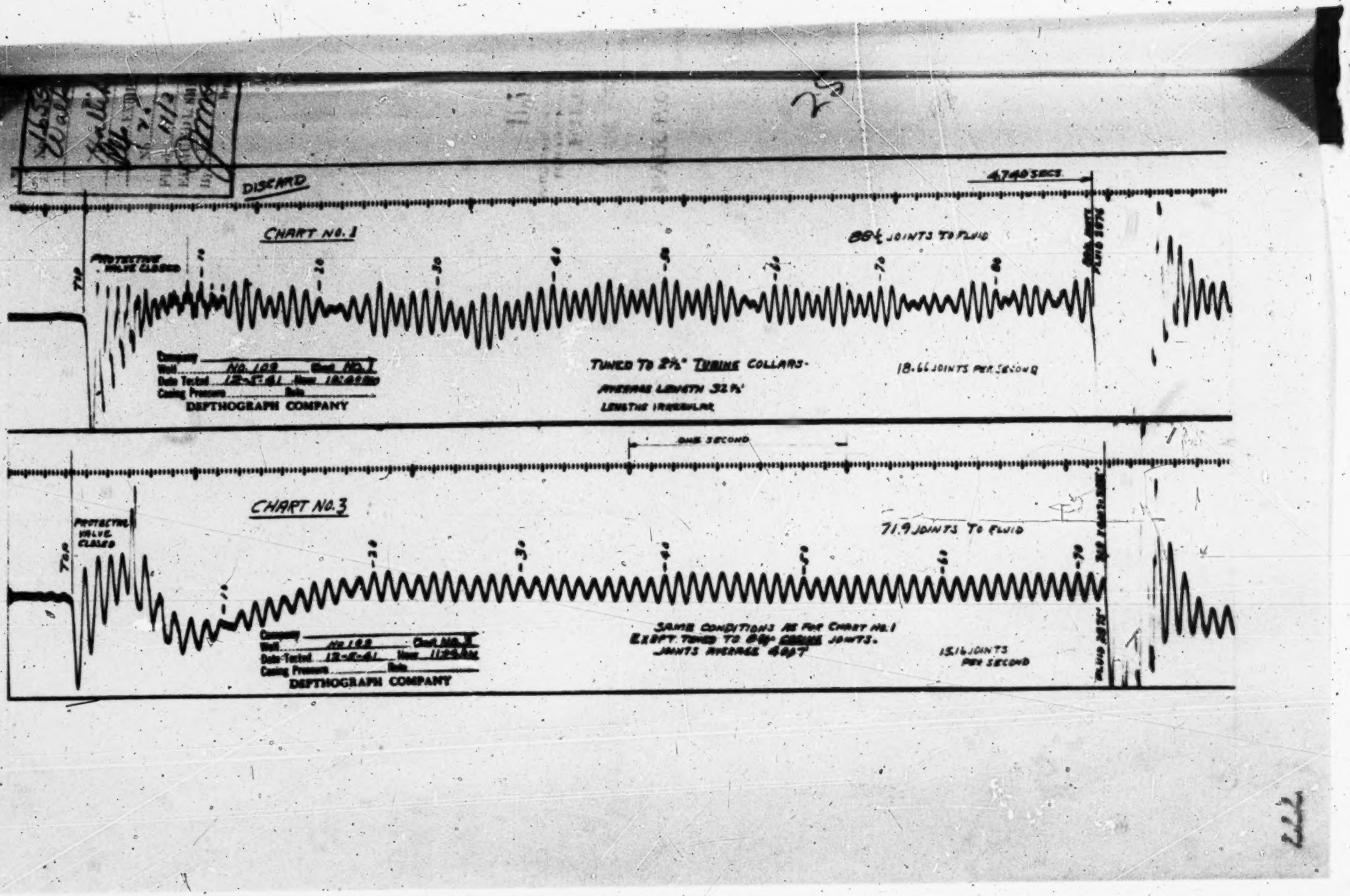
(valve opened)

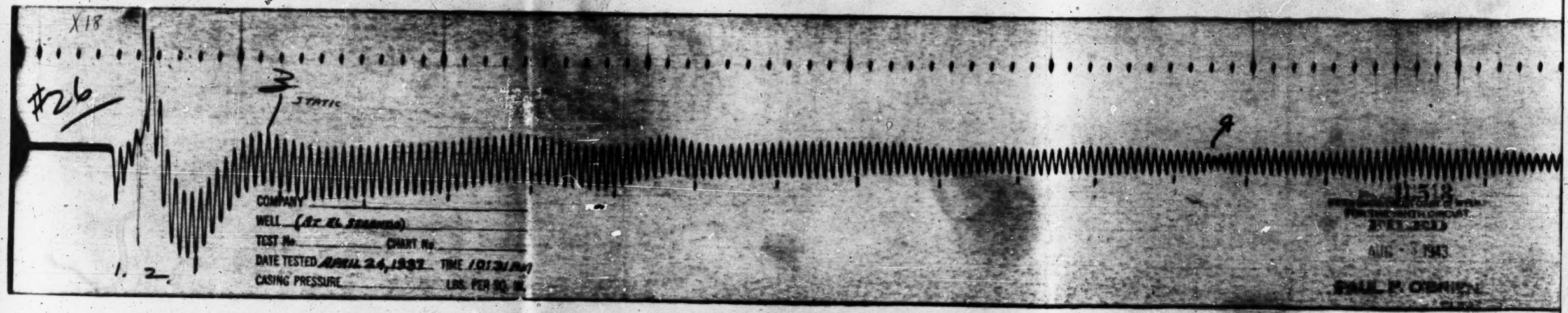
100 Shot



Nesa No1 Test Made May 7, 1936 11 35 AM
TUBING OUT OF THE HOLE

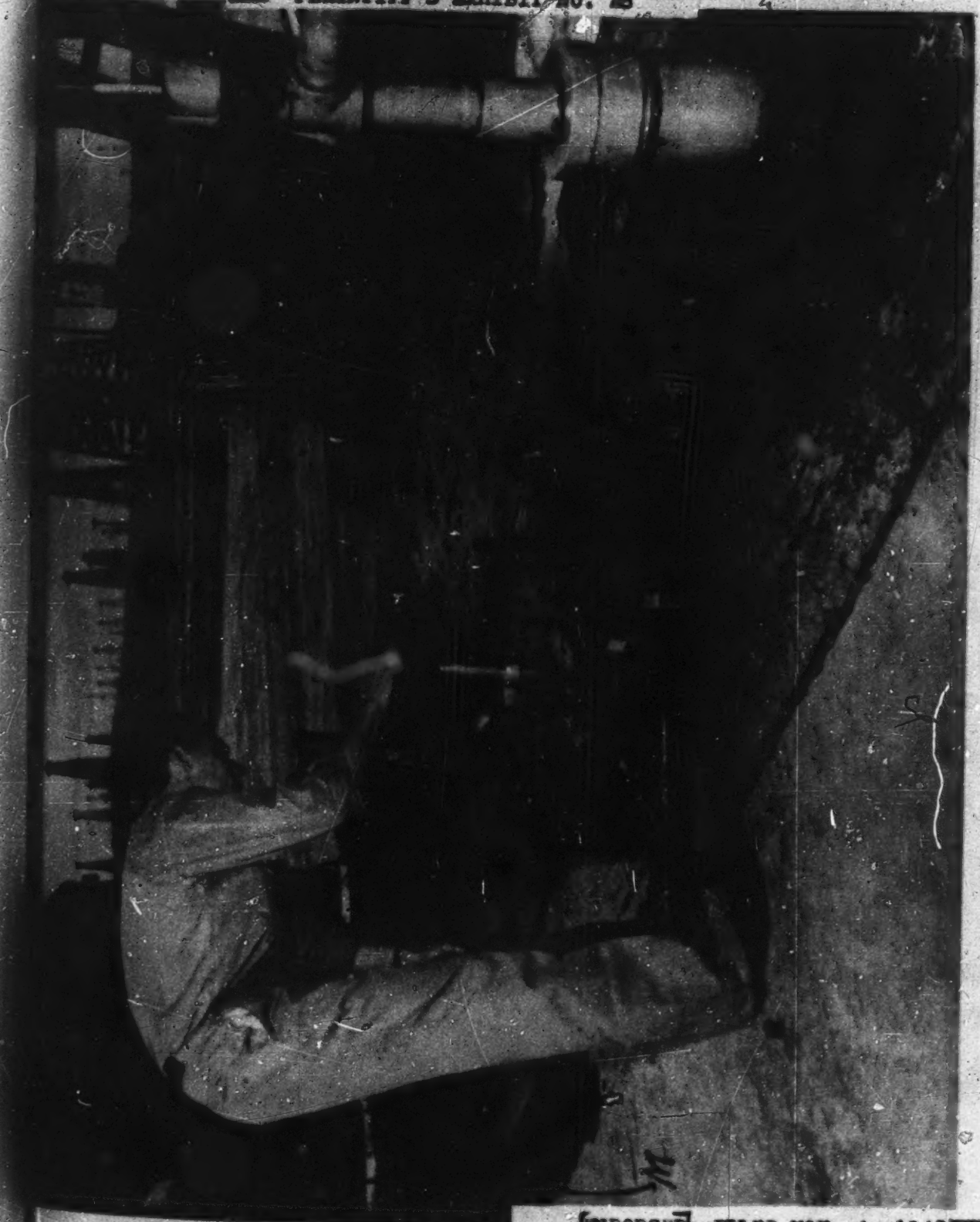
No. 1656-PH
Walter
Halliburton
et al. EXHIBIT
No. 14
Filed 11/3 1936
EDMUND L. SMITH, Clerk
By
Deputy Clerk


DISCARD
4.740 SECS
CHART NO. 1
PROTECTIVE VALVE CLOSED
TOP
88½ JOINTS TO FLUID
FLUID LEVEL
Company
Well NO. 102 Chart NO. 1
Date Tested 12-6-61 Hour 10:05 Am
Casing Pressure Bale
DEPTHOGRAPH COMPANY
TUNED TO 2⅞" TUBING COLLARS.
AVERAGE LENGTH 32 Ft'
LENGTHS IRREGULAR
18.66 JOINTS PER SECOND
ONE SECOND
CHART NO. 3
PROTECTIVE VALVE CLOSED
TOP
71.9 JOINTS TO FLUID
FLUID LEVEL
Company
Well NO. 102 Chart NO. 3
Date Tested 12-6-61 Hour 11:25 Am
Casing Pressure Bale
DEPTHOGRAPH COMPANY
SAME CONDITIONS AS FOR CHART NO. 1
EXCEPT TUNED TO 8 JOINTS.
JOINTS AVERAGE 40 FT
15.16 JOINTS PER SECOND

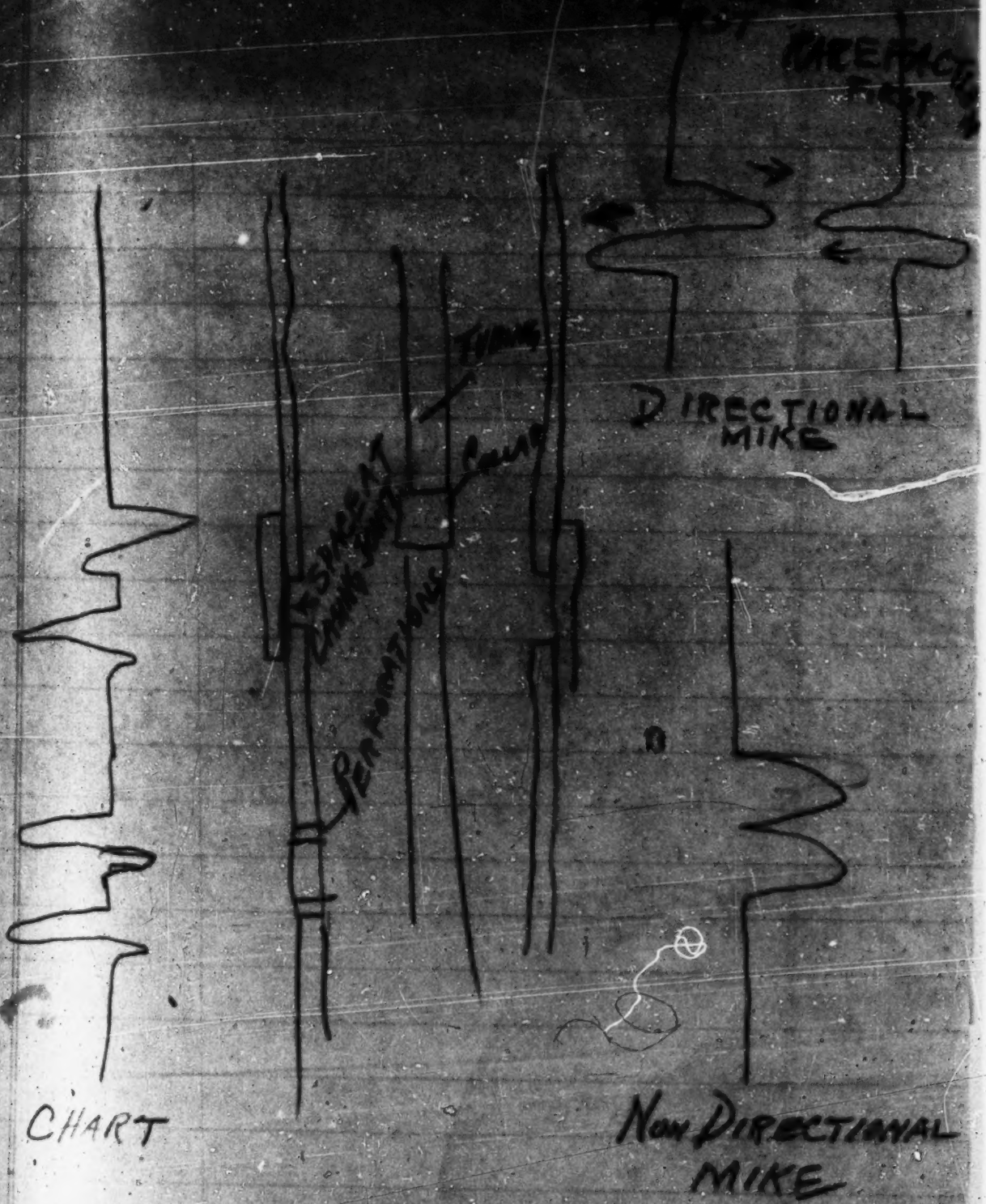

X18
#26
3
STATIC
1. 2.
COMPANY
WELL (Ar. El. Sesame)
TEST No. CHART No.
DATE TESTED APRIL 24, 1937 TIME
CASING PRESSURE LBS. PER SQ. IN.
1518
AUG - 3 1943
PAUL P. O'BRIEN

FILED NOV. 4, 1942
PLAINTIFF'S EXHIBIT NO. 27

PLAINTIFF'S EXHIBIT NO. 23



[ENDORSED] FILED NOV. 4, 1942



No. 6552-PH
Walker
vs.
Hollingsworth
DEFENDANT'S EXHIBIT
No. 2
Filed 11/5 1943
EDMUND L. SMITH, Clerk
By
Deputy Clerk

No. 1518
UNITED STATES CIRCUIT COURT OF APPEALS
FOR THE NINTH CIRCUIT
FILED
AUG - 3 1943